DEVELOPMENT OF A COST-EFFECTIVE METHOD TO IMPLEMENT TRAFFIC MANAGEMENT PRINCIPLES TO A SMALL CITY ENVIRONMENT

by

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DECLARATION

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ABSTRACT

Small cities, defined as cities with a population of at most 300,000 people, would benefit from a Traffic Management Centre (TMC) to improve traffic operations but the model used for larger cities is often too expensive to implement. This research therefore investigates a cost effective traffic management model for a small-city environment. This traffic management model would be able to provide the necessary functionality of traffic management inherited from TMCs for a larger city. Two Test Models (TMs) were investigated which assessed the difference in functionality provided by conventional TMC practices (TM 1) and a proposed "minimal infrastructure model" (TM 2) to determine an optimal traffic management method that is cost-effective. The four core Intelligent Transport Systems (ITSs) that were identified for a small-city include: Arterial Management System (AMS), Incident Management System (IMS), Urban Traffic Management (UTM) and Transport Information Management (TIM). These four systems were tested within the study area of Stellenbosch. The level of functionality of the two TMs were compared. Unmanned Aerial Vehicles (UAVs), also known as drones, and Floating Car Data (FCD) were additional tools used in TM 2 in the attempt to achieve effective traffic management with minimal fixed infrastructure requirements. The TMs were investigated for the town of Stellenbosch, in the Western Cape of South Africa. This is a small city environment with significant traffic challenges, and which currently does not have a TMC. It was found that the level of detail in TMC operations required for larger cities is not the same as for smaller cities. In addition to this, effective traffic management can be provided to a small city by implementing the minimal infrastructure model (TM 2). Furthermore, it was found that by reducing the number of components on the roads of the study area and including FCD and UAVs to aid traffic management, the TMC capital and first year of operation cost could be reduced by 37% for the minimal infrastructure model, when compared to the traditional TMC setup used in large cities in South Africa.

Keywords: Traffic management; Test Models; cost-effective traffic management; Floating Car Data, Unmanned Aerial Vehicles

OPSOMMING

Klein stede, gedefinieer as stede met ‘n bevolking van hoogstens 100,000 mense, sal voordeel trek uit verkeersbestuursentrums om verkeersbedrywigheede te verbeter. Die model wat vir groter stede gebruik word, is egter dikwels te duur om te implementeer. Hierdie navorsing ondersoek ‘n koste-effektiewe verkeersbestuursmodel vir ‘n klein stadsomgewing wat die nodige verkeersbestuur funksionaliteit kan beërf wat van groter verkeersbestuursentrums geërf word. Twee toetsmodelle is ondersoek wat die verskil in funksionaliteit van konvensionele verkeersbestuursentrums (Toestmodel 1) en ‘n voorgestelde ‘minimale infrastruktuurmodel’ (Toetsmodel 2) beoordeel om ‘n optimale verkeersbestuurmetode te bepaal wat kostedoeltreffend is. Die vier kern Intelligente vervoerstelsels wat vir ‘n klein stad geïdentifiseer is, sluit in: ‘n arteriële bestuurstelsel, n’ voorvalbestuurstelsel, stedelike verkeersbestuur en vervoerinligtingbestuur. Hierdie vier stelsels is binne die studiegebied van Stellenbosch getoets en die vlak van funksionaliteit van die twee toetsmodelle is vergelyk. Onbemande lugvoertuie en drywende motordata was addisionele instrumente wat gebruik is in die poging om doeltreffende verkeersbestuur te bereik met minimale vaste infrastruktuurvereistes. Die toetsmodelle is ondersoek vir die stad Stellenbosch in die Wes-Kaap van Suid-Afrika. Dit is ‘n klein stadsomgewing met beduidende verkeersuitdagings, en wat tans nie ‘n verkeersbestuursentrum het nie. Daar is gevind dat die verkeersbestuursentrumbedrywighede detailvlak wat vir groter stede benodig word nie dieselfde is as vir kleiner stede nie en dat effektiewe verkeersbestuur aan ‘n klein stad verskaf kan word deur die implementering van die minimale infrastruktuurmodel. Dit is bevind dat duer die aantal komponente op die paaie van die studiegebied te verminder en met die inbegrip van drywende motordata en onbemande lugvoertuie om verkeersbestuur te help, kan die kapitaal van die verkeersbestuursentrum en die eerste jaar van die bedryfskoste met 37% verminder word vir die minimale infrastruktuurmodel, in vergelyking met die tradisionele opset vir verkeersbestuursentrums wat in groot stede in Suid-Afrika gebruik word.

Sleutelwoorde: Verkeersbestuur, Toetsmodelle, koste-effektiewe verkeersbestuur, drywende motordata, onbemande lugvoertuie

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Chapter 1: Introduction

1.1 Background

Traffic management plays an integral role in ensuring efficient traffic flows through the road network. This management is often done from a central locale such as Traffic Management Centres (TMCs). The use of a dedicated TMC helps regulate traffic flow as well as provide a timeous response to accidents or road incidents, which in turn eases the flow of traffic by reducing congestion. These management centres house various systems and processes that work together. The different components of these systems gather, sort and analyse data, and require skilled practitioners to operate effectively since one process cannot work properly without the other.

The Department of Transport (DoT) made progress in 1998 towards the creation of a traffic management platform by establishing the South African National Roads Agency Limited (SANRAL). Part of SANRAL's mandate is to allow for better management of South Africa's roads and road incidents (Department of Transport, 2011). The increase in population over the years has led to ever increasing traffic levels, making traffic management of the road network vital to keep the number of road incidents to a minimum.

Now, due to rapid urbanisation, an increase in population and the increase in non-motorised transport (NMT), Intelligent Transportation Systems (ITS) are being sought out to provide innovative ways to manage traffic in cities. An ITS-based TMC centre opens possibilities for innovative traffic management. To date, TMCs and active traffic management have only been implemented in very large cities in South Africa (specifically Cape Town, eThekwini and the Gauteng metropolitan areas including Tshwane, Johannesburg and Ekurhuleni). This research however considers an appropriate TMC model to be tested for smaller city areas. An ITS-based TMC can incorporate new technologies such as analysis of Big Data and the use of drones to aid in traffic management which could be beneficial in providing efficient traffic management. The TMC case studies will be investigated through definition of costing and traffic management models drafted to determine the need of a TMC for the given area. These models will assess different aspects of the TMC to determine the economic value and the impact the introduction of the TMC would have on the given city.

Stellenbosch is selected as the test area for this research since it is a relatively small town with high traffic congestion. Stellenbosch is a university town in South Africa, situated in the Western Cape, and is characterised by the surrounding vineyards of the Cape Winelands and mountainous nature reserves. For the design of an efficient TMC model for the town and its inhabitants, this TMC model can be used as a base reference model for other small cities nationwide. The town of Stellenbosch also incorporates different transport modes and it is a suitable test area for which future management strategies can be based on to ensure better traffic management for the Western Cape and also South Africa.

Stellenbosch currently does not have a dedicated TMC to assist with traffic management. Traffic is controlled via traffic signals, stop control and roundabouts and closed-circuit television (CCTV) footage along certain roads is monitored by Stellenbosch's Division of Safety and Security, however is not used for traffic observation. The addition of TMC processes to this existing transport network and cohesion between the parties involved in traffic management (traffic law enforcement, the emergency response unit and fire and rescue unit) would, theoretically, see an improvement in incident response time and traffic management. This research project will determine if theoretical improvement can be achieved and the costs associated with traffic management in Stellenbosch.

Further motivation for this research to be conducted to Stellenbosch includes:

- There is a tremendous inflow of vehicles to Stellenbosch during the morning peak hour (and out of Stellenbosch again in the afternoon) due to strong trip attractions in the town including Stellenbosch University, business and tourism, while residential availability in Stellenbosch is limited.
- From 2011 to 2018, the population of Stellenbosch has grown from 155,728 to 186,730 people, nearly a 20% population growth over 7 years (Western Cape Government, 2018).
- The number of traffic offences in Stellenbosch has increased, for example Driving Under the Influence of substances (DUI) cases increased from 99 to 189 between 2016 and 2018 (Western Cape Government, 2018).
- In 2017, there were a total of 32 fatal crashes and 34 road user fatalities in Stellenbosch (Western Cape Government, 2018).
- As of 31 January 2019, there were 49,810 licensed vehicles in Stellenbosch with 30,761 of those being light passenger motor vehicles (Western Cape Government, 2019).

1.2 Problem statement

Small cities, defined generally as cities with a population of less than 300,000 but more than 2,500 people, could benefit from a TMC but the TMC model used in larger cities is usually too expensive to implement here. Therefore, a traffic management model for a small city environment needs to be developed that provides the necessary traffic management functionality while also being cost effective enough to implement.

1.3 Objectives

The overall goal of this research project is to develop a cost-effective TMC for a small city environment. The objectives for this research project that will allow the problem statement to be addressed are as follows:

Objective 1

Evaluate the systems and processes that traditional TMCs are comprised of through an extensive review of literature. Thereafter evaluate how traffic is managed with Unmanned Aerial Vehicles (UAVs) and how Floating Car Data (FCD) is used for traffic management purposes.

- Provide background of the components present in TMCs, characteristics of these components, and how Intelligent Transport Systems (ITS), including Floating Car Data (FCD) aids TMCs to manage traffic more efficiently.
- Provide information of how TMCs operate in countries around the world.
- Provide background of Unmanned Aerial Vehicles (UAVs) and how these can be used to aid in traffic management. The systems that UAVs comprise of will also be stated, together with detailed analyses regarding characteristics relating to number of UAVs and UAV type, flight patterns and trajectories, data collection and processing methods as well as correspondence between UAVs and TMC.

Objective 2

Develop two Test Models (TMs) that assesses different methods of traffic management: one model that implements traditional TMC traffic management components and a model that replaces some components with UAVs and FCD as a cost-effective method of managing traffic in a small city.

- Develop the following four systems for the test area: Arterial Management System (AMS), Incident Management System (IMS), Transport Information Management (TIM) and Urban Traffic Management (UTM) for TM 1.
- Develop TM 2 based on reducing the number of components in TM 1 and introducing UAVs and FCD.
- Provide a cost breakdown for both TM 1 and TM 2.

Objective 3

Determine the level of functionality that is lost due to limited infrastructure in TM 2 and provide reasoning, including an economic evaluation, as to why TM 2 should be implemented for traffic management in a small city environment.

1.4 Study area

The town of Stellenbosch was chosen to be the test area for this research. As of 2018, the population of Stellenbosch is over 186,730 people, with 133,357 of these people within the working age group of 15 – 64 years. The presence of a university at the centre of the town further increases the congestion and affects the traffic flow throughout the town, which motivates the study area choice. Due to its relatively small size and diversity in characteristics of the driver population, it will provide a good dataset that can be used to help aid the research in this report. Based off statistics of 2016, Stellenbosch's tertiary sector is the highest contributor to the GDP with a 69.8% contribution, followed by the secondary and primary sectors with contributions of 24% and 6.2% respectively. The tertiary sector is the main contributor to employment in Stellenbosch with a 69.5% contribution. Retail trade and business services are the highest contributors to both GDP and employment within the tertiary sector (Western Cape Government, 2018). The section of Stellenbosch chosen to be assessed is indicated in Figure 1-1.

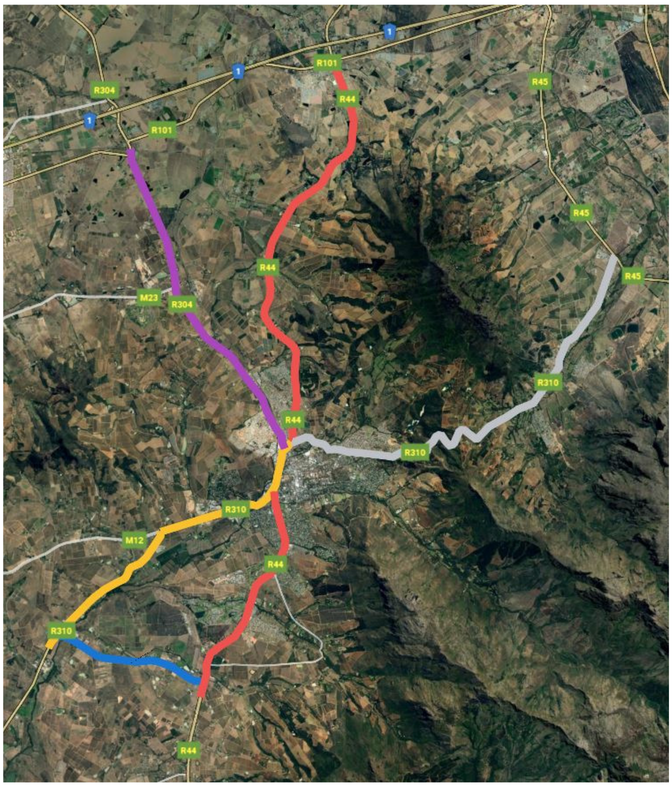

Figure 1-1: Study area for research (↑N) (Google Earth, 2020)

In more detail, the area chosen for this study is indicated by the intersections along the following arterials, expanding from Central Stellenbosch:

- The intersection of the R310 and Annandale Road south-west of Central Stellenbosch
- The intersection of the R44 and Annandale Road south of Central Stellenbosch
- The intersection of the R304 and the R101 (Old Paarl Road) north-west of Central Stellenbosch
- The intersection of the R44 and the R101 (Old Paarl Road) north-east of Central Stellenbosch
- The intersection of the R310 (Helshoogte Road) and the R45 north-west of Central Stellenbosch

This study area was chosen based on an analysis of the traffic volumes for the morning (7:00 – 8:00 am) and afternoon (16:00 – 17:00 pm) peak hours. *Google Maps* was used in this analysis, which provided colour-coded traffic indications along various routes in Stellenbosch. Slower moving traffic is indicated in dark red and faster moving traffic in green. These speeds are important because it indicates where more attention should be given with regards to traffic management. Furthermore, the boundaries were decided on due to the study area being within Stellenbosch Municipality's coverage. This is because only traffic within the coverage of Stellenbosch Municipality is being assessed.

1.5 Research significance

There is no TMC in Stellenbosch. Dedicated traffic management processes for the town of Stellenbosch would allow for quicker reaction time to incidents, better management of traffic services and an overall increase in efficiency of the road network. This will also allow for better management on a microscopic level since detailed analyses of other operations can also be done, such as non-motorised transport (NMT) and microscopic issues from pedestrians and cyclists can be dealt with and used to better improve the state of management in Stellenbosch. Although Stellenbosch has a population of less than 300,000 people, it is choked by traffic jams in the peak periods and successfully implementing traffic management processes will significantly aid management of these conditions. In addition to this, the incorporation of UAVs in traffic management and whether or not UAVs aid the management of traffic incidents and improve response times to incidents will be investigated.

1.6 Chapter Breakdown

The following chapters in this report consists of the following information:

- **Chapter 2 – Review of literature on TMCs and its components**: This chapter provides research related to the different systems of traffic management. This includes a description of the different Traffic Management System (TMS) phases and management thereof, which are Information Gathering, Information Processing and Service Delivery. This chapter also describes traffic management processes in South Africa and in countries around the world, as well as how UAVs are currently used in traffic management globally. An analysis of the UAV framework followed for traffic management and an overview of the existing regulations related to using UAVs in South Africa are also provided.
- **Chapter 3 – Methodology**: Chapter 3 provides information relating to the study area for the two Test Models. Data collection and analysis methods as well as limitations of this study are provided in Chapter 3.
- **Chapter 4 – Test Model 1 (TM 1)**: Chapter 4 describes Test Model 1. The different systems associated with TM 1 as well as a cost breakdown is provided in Chapter 4.
- **Chapter 5 – Test Model 2 (TM 2)**: Chapter 5 describes Test Model 2. The different systems associated with TM 2 as well as a cost breakdown is provided in Chapter 5.
- **Chapter 6 – Functionality assessment**: Chapter 6 assesses the difference in traffic management capability of TM 1 and TM 2 by comparing different fields of traffic management from the two TMs. An economic evaluation for the two TMs is also provided in Chapter 6.
- **Chapter 7 – Conclusion and recommendations**: A conclusion to this study is provided in Chapter 7. Chapter 7 also checks whether or not the research objectives are met. Finally, recommendations related to this study and for future research are provided in Chapter 7.

Chapter 2: Review of Literature

2.1 Introduction

This chapter provides a literature review of Traffic Management Systems (TMSs) that occur within a Traffic Management Centre (TMC). The classification of TMSs and the phases of a TMS is provided. The management of TMSs and the different roles of a TMS within a TMC are provided. Characteristics such as responsibility, costs associated and agencies involved with the running and management of TMCs are investigated and the definition of and benefits that Intelligent Transportation Systems (ITS) provides to traffic management are also provided. The traffic conditions and of different cities around the world and how these cities manage traffic are provided, followed by a review of literature relating to the role and function of the South African Road Traffic Management Corporation (RTMC). Finally, literature relating to the use of Unmanned Aerial Vehicles (UAVs, also called drones) is provided which includes a description of how UAVs have been used in traffic management and the laws associated with the use of UAVs.

2.2 Traffic Management Systems: Classification and management

Traffic congestion has three key sources. Firstly, events that influence traffic, such as working zones, weather conditions and traffic incidents are considered to influence traffic congestion. The second source is related to traffic demand, which is fluctuations in normal traffic during peak times and special events. The last source of congestion is caused by limitations of the infrastructure for transport services, which includes the traffic control devices and physical bottlenecks (de Souza, et al., 2017).

With these three sources of congestion understood, large cities can focus on preventing traffic congestion using Traffic Management Systems (TMSs), which are processes implemented by Traffic Management Centres (TMCs). TMSs are composed of a set of applications and management tools to integrate communication, traffic data and processing technologies (Ismail & Venter, 2007). TMCs are facilities dedicated to implement the processes of TMSs, such as data collection of traffic data streams and management of traffic infrastructure. Traffic incidents can be identified and consequently controlled by exploiting the traffic-related data obtained and analysing it in TMCs, improving the overall traffic efficiency and providing a smooth traffic flow (de Souza, et al., 2017).

TMSs are composed of many different building blocks that work co-dependently to ensure efficient management of the road network. Information is gathered from the vehicles and road sensors and this information is processed to deliver information regarding incidents, route guidance and traffic conditions. This information is used to assess the road network and to provide updates along the routes that are managed by the TMC.

2.3 Phases of a TMS

By exploiting traffic-related data, TMSs can provide services that can possibly improve traffic efficiency and safety, as well as decrease incident response time, although not directly measured. This is done through three key phases:

1. Information gathering, which is the collection of data from heterogeneous/automated sources.
2. Information processing, which refers to the collection and processing of received traffic data to further identify traffic hazards that affect efficiency, and
3. Service delivery, which provides services to control hazards in traffic and other traffic-related issues in order to improve the overall efficient on the road network (de Souza, et al., 2017).

Figure 2-1 indicates these three phases and how they are interrelated. In more detail, the phases are described in more detail with reference to Figure 2-1.

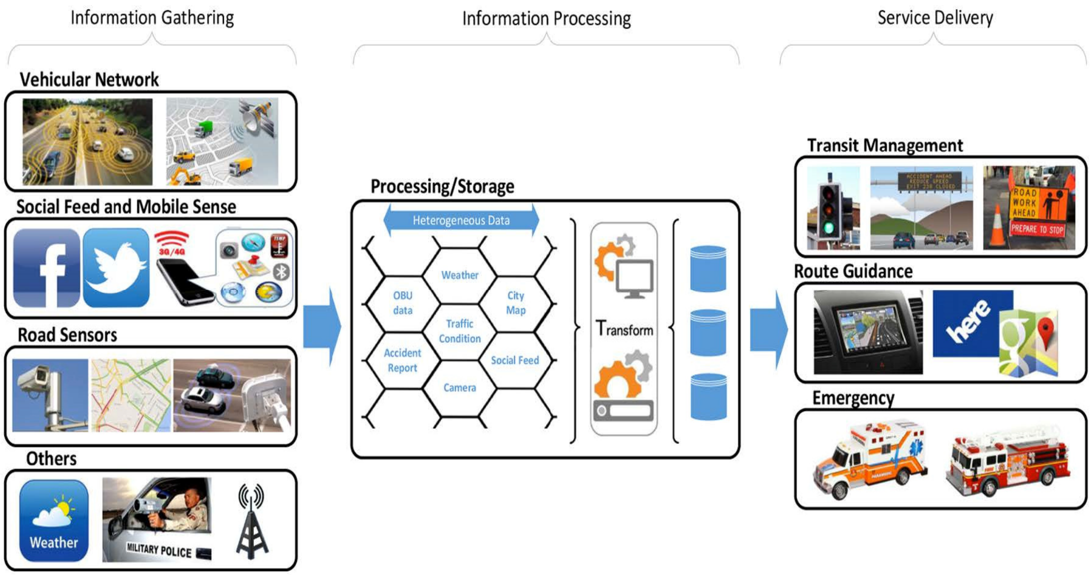

Figure 2-1: Three phases of a TMS (de Souza, et al., 2017)

2.3.1 Information gathering

Information gathering refers to the collection of traffic data from different sources such as vehicles, in-road and roadside sensors, roadside units, traffic lights and various participatory networks. Regarding vehicles, traffic data are collected from built-in sensors, such as GPS. This is therefore aggregated in the on-board units of the vehicles to be sent to the TMC to be analysed and used.

Moreover, for roadside sensors as well as sensors in roadways, the traffic-related data rely on traffic-light phase and timing, traffic history, traffic incidents, road occupancy, and weather conditions (de Souza, et al., 2017). The accuracy of the services delivered by the TMSs can be increased by sources that are publicly available, as well as by participatory sensing networks. This is because the traffic data collected from these sources can identify population habits and city characteristics, which improves accuracy of traffic data. Data used by people's everyday activities on social media such as Twitter, Instagram or Facebook can be used to forecast congested areas according to the time and the day of the week. Phase transitions in areas that are congested can be altered to prevent congestion and allow for a better flow of traffic. This information can also be used to notify road users about the time delay it would take if travelling on a congested route, via their GPS (de Souza, et al., 2017).

2.3.2 Information processing

Once traffic data is obtained, it needs to be processed so that traffic hazards can attempt to be forecasted. Due to TMS characteristics, this processing can be done in either an infrastructure-based or infrastructure-free manner. Information obtained from vehicles that is processed in an infrastructure-based manner rely on a central server, such as a TMC or any other location that has the appropriate information processing capabilities, so that traffic data can be assessed in order to identify possible traffic hazards. Here, a longer range of communication is allowed. Information processed in an infrastructure-free manner occurs through a full distributed service whereby all vehicles share their traffic data with each other using only V2V communication. Here, each vehicle can locally identify traffic hazards. The range of communication is shorter in infrastructure-free processing as compared to infrastructure-based processing (de Souza, et al., 2017).

Further functionality and roles of the different components of a TMS are provided in Section 2.4 which deals with the management components for a TMS.

2.3.3 Service delivery

Service delivery provides services to alleviate or deal with the traffic issues determined in the two phases prior. Services can be delivered either infrastructure-free or based on the infrastructure present. Examples of services include congestion detection and avoidance, accident warning and route re-evaluation (as on GPS), among others (de Souza, et al., 2017).

Thanks to connected vehicles, two types of communication are provided in a TMS, namely vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I). V2V communications are used in the communication between vehicles, which is data exchange via location or Bluetooth. V2I communication occurs when a vehicle needs to send or receive information from a central entity, such as a TMC. Figure 2-2 indicates the overall architecture of how V2V and V2I systems are associated.

Modern TMCs use a system based on *connected vehicles*, which provides an exchange of data between roadside units, vehicles and the TMC (de Souza, et al., 2017). In these networks, the vehicles are mobile nodes with an on-board unit that has sensors embedded in it as well as processing units which is used as links between the vehicles and TMC in the acquiring of data to help alleviate traffic congestion and sort out other traffic-related issues.

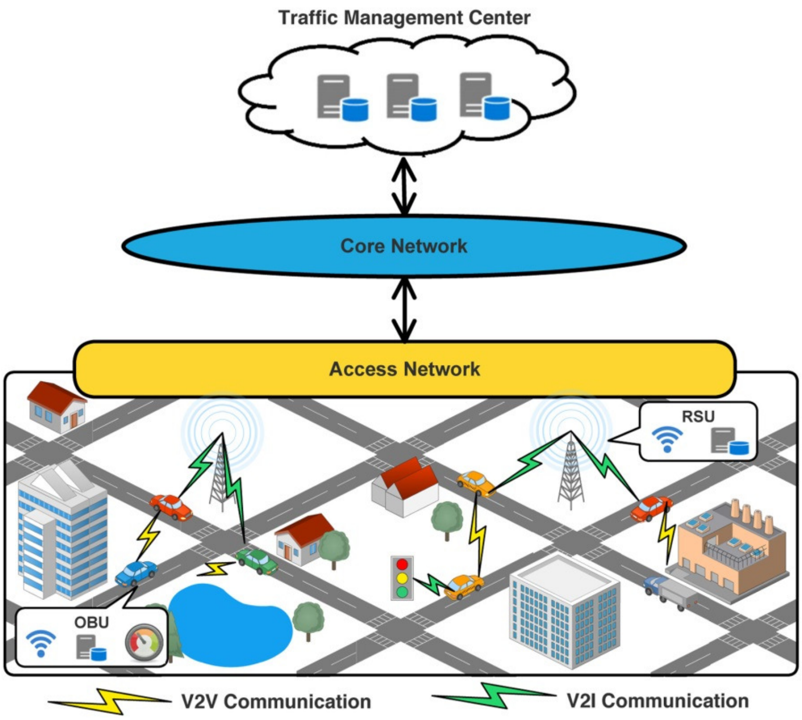

Figure 2-2: V2V and V2I communication (de Souza, et al., 2017)

Figure 2-2 indicates how vehicles can collect traffic-related data through their on-board units and send such data to vehicles nearby using V2V communication or to a TMC using V2I communication through an access network. Roadside units and sensors can collect traffic-related data and send it to the TMC to be used. In this way, the TMC acts as the core network and provide many important functions, such as aggregation, authentication, switching and routing of traffic data. Many different sources can provide information to be used through the core network, thus improving the services delivered by the TMS (de Souza, et al., 2017).

2.4 Management components of a TMS

In South Africa, road traffic practices that aim to reduce the road traffic casualty rates by 50% from 2011 to 2020 were implemented under the supervision of the DoT and is in line with the United Nations Decade of Action for Road Safety. The UN Decade of Action for Road Safety, an international road safety programme, initiated in the hopes of helping signatory countries such as South Africa to reduce its road traffic casualties by 50% between 2011 and 2020 (United Nations at the UN General Assembly, 2010). South Africa's Department of Transport (DoT) developed the National Road Safety Strategy (NRSS) 2016 and extended its timeframe to 2030 in line with the National Development Plan (Department of Transport, 2011). A discussion of the implementation of the developed and new road traffic management models are presented as well. New models consist of management models to deal with situations such as non-wearing of seatbelts, risk assessment, data collection and analysis and accident management (Mohlala, 2015).

2.4.1 The role of a TMS

A TMS is composed of three units, which are a Physical Component, a Unit Component and a Management Component, as indicated in Figure 2-3. The Physical Component covers road users, vehicles, road sections. The Unit Component is formed from two or more elements from the collection/sub collection of the physical component, such as road environment units, pedestrian units, driver units and vehicle units. These units are operational and should be regulated, controlled and managed through road user conduct, applying self-regulation and/or self-control principles, and the authorities, which should establish measures to regulate and/or control traffic units. The Management Component has the function to enable role-players to manage orderly road traffic and traffic safety in a scientific, holistically, integrated and coordinated manner to reduce traffic casualties (Mohlala, 2015).

The disciplines and functional areas of the TMS are aligned with the five pillars of the UN DoA, namely:

1. Road Safety Management
2. Safe Vehicles
3. Safe Road users
4. Post-crash Response
5. Safer Roads and Mobility

Monitoring and evaluation are also considered as roles of the TMS as to consider what works, why it does or does not work, and who was/were affected by incidents. To reduce road traffic casualties, the following need to be considered:

1. High level of political support and community involvement
2. An adequate supply of resources such as finances and personnel needs to be present
3. Administration, co-operation and co-ordination need to be of excellent quality.

If all these can be properly implemented, it can improve the quality of road usage in South Africa.

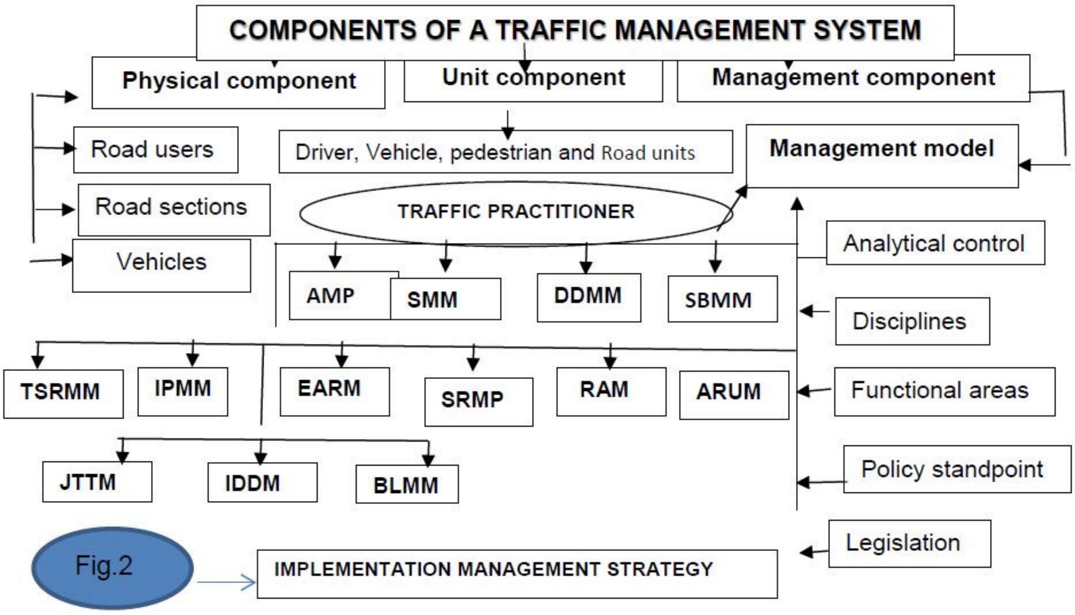

Figure 2-3: Components of a TMS and their inter-relations (Mohlala, 2015)

2.4.2 The role of the TMC that implements TMSs

TMCs provide a physical location to house components, hardware and software required to carry out TMSs. It is the nerve centre of a Transportation System Operations Program (TSOP). Key functions of a TMC include:

- Monitoring of system performance
- Act as communication hub for traveller information
- Manage planned and unplanned events
- Operation optimisation of the transportation system
- Engage, convene and coordinate stakeholders
- Act as a hub to provide regional traffic management of the road network

(Pretorius, et al., 2019).

TMCs differ with regards to freeway and arterial management. Functions of freeway management operations include monitoring congestion, providing support for incident management, detecting, verifying and reacting to freeway incidents, monitoring hardware such as ramp meters and Variable Message Sign (VMS) boards, and dissecting traveller information (data obtained from social media, vehicle probes, and other data sources used to provide information to the public via VMS boards, social media). Arterial management operations differ only on scale based on the road network capacity. Both freeway and arterial management require coordination between relevant stakeholders, including Emergency Medical Services, Police Services and Fire and Rescue Services among others (Pretorius, et al., 2019).

2.4.3 Road Traffic Models

Under the TMS as the sub-system of the Transport System (TS), the proper implementation of the developed road traffic models, coupled with the disciplines and functional areas as demonstrate in Figure 2-3, can minimize the traffic violation risks that are contributing to traffic fatalities in South Africa. Figure 2-3 also demonstrates two categories of the developed road traffic models in South Africa that need to be implemented. Category 1 covers those models that are implemented and are in operation and Category 2 covers developed models that are not yet implemented. The Category 1 and 2 models have been developed to reduce high risk offences that are contributory factors to traffic causalities. The components of a TMS are indicated in Figure 2-3.

From Figure 2-3, the different abbreviations refer to different models that can assist to reduce traffic casualties in South Africa, if implemented/maintained correctly, as suggested by Mohlala (2015). These models are developed and implemented to Limpopo's current TMS. These are:

1. Accident Management Procedure (AMP)

   The procedure, as described by Mohlala (2015) should be implemented to assess, monitor and manage accidents to produce a reduction in the number of accidents and a quicker response time so that traffic does not congest for too long.
2. Speed Management Model (SMM)

   The implementation of an SMM can reduce the amount of casualties that are caused by speeding. An SMM for Limpopo will be based on the Quality Control Management (QCM) that was developed by The Council for Scientific and Industrial Research (CSIR).
3. Drunken Driving Management Model (DDMM)

   Campaigns are in place in order to reduce and possibly prevent the occurrence of drunk drivers in SA. This model needs to be strictly implemented and maintained to ensure that there are little to no drunk drivers on the roads. More than 60% of fatal crashes occur as a result of alcohol abuse and drunk driving as mentioned by the Arrive Alive Campaign (Arrive Alive, 2014).
4. The Seatbelt Management Model (SBMM)

   Research has shown that a better implementation of laws enforcing the wearing of seatbelts, both front and rear of the vehicle, can reduce fatalities by 25 – 30% (Department of Transport, 2011).

There are various other models that can be developed to be implemented to assist TMC operations in reducing casualties and incidents on the road. These models not only assists in the prevention or mitigation of traffic incidents, but also aims to improve aspects such as data collection and processing, educating school children about traffic safety, risk assessment procedures and incident response time. Mohlala (2015) describes a few of these models that can be implemented in areas classified mainly as rural as shown in Figure 2-3. These are:

1. Time and Space Road Management Model (TSRMM)
   This model aims to improve the safety of road users and minimise the risk of accidents on the road network. This model may not be directly implemented to a TMC or its operations although the ultimate goal of the model is concurrent with the overarching goals of a TMC (Kockott, 2009).
2. Integrated Pedestrian Management Model (IPMM)
   This model aims to promote safety and safe practices for pedestrians and to reduce the number of pedestrian casualties on the road through various sub-models that deal with improving pedestrian facilities and accesses (Mohlala, 2015).
3. Enhancement of Accident Reporting Model (EARM)
   This model will explore ways in which the process of road traffic accident reporting could be enhanced. The objective of this model was to examine the process that road authorities follow to report accidents and focus on an analysis of three characteristics of this data collection. These characteristics are: The quality of completed road accident reports, The time it takes the relevant authorities to report accidents and other activities occurring on the road network, and the general experiences that drivers involved in road traffic accidents have regarding processes to report an accident they are in or have witnessed. The model then aims to draft guidelines for the improvement of these characteristics (Rothe, 2008).
4. Star Rating Monitoring Procedure (SRMP)
   This model aims to reduce negative attitudes and lawlessness of taxi drivers and in the minibus taxi industry as well as to decrease the high level of conflicts and killings in South Africa which occur through violence in the minibus industry. This model assesses the current condition of taxi violence in South Africa and various aspects that contribute to this violence (Ratau & Pretorius, 2008).
5. The Risk Assessment Model (RAM)
   The conventional procedure to measure the success rate of accident prevention on roads used globally is when countries use accident rates in comparison with other countries to determine their relative level of safety on the road network. To improve this result, this

trend analysis could be complemented with a risk analysis that municipal authorities could carry out. Although risks are normally formulated in terms of the theory of probability, a Risk Score Value could be of further benefit to road traffic managers by allowing authorities to conduct cost effectiveness studies and to prioritise countermeasures with a holistic overview to reduce road operation risks to its minimal/an acceptable level (Pretorius, et al., 2010).

6. Accident Response Unit Model (ARUM)

   This model aims to improve the response time and methods to accidents occurring on the road network through assessment and improvement of the current Accident Response System in place (Mohlala, 2015).

7. Junior Traffic Training Model (JTTM)

   Many children in low income areas have to walk to get to school, a public library, for visiting purposes and for many other reasons. These children are susceptible to pedestrian incidents and need to be properly trained in order to understand road safety and promote it in their living environment to their peers. Therefore, the Department of Transport (DoT) and Public Works Road Safety Management (RSM) directorate along with Education Departments throughout South Africa have developed a new Junior Traffic Training Centre (JTTC) . JTTCs are small-scale simulated road environments where primary school learners can learn and practice good road safety habits. Primary school learners are the target audience for the RSM because they are relatively more vulnerable to accidents than adults and learning good road safety habits at an early age will ensure a safer environment with a reduction in pedestrian accidents and fatalities (Western Cape Government, 2019).

8. Integrated Databank and Database Model (IDDM)

   Mynhardt et al (2013) undertook a study to determine if there was enough data to counter road traffic crashes in South Africa. A study was conducted in the development of a model that would provide pointers for establishing and maintaining a scientifically accountable National Road Traffic Safety Databank (NRTSD). The objectives of the study were to assess the current methodologies of data gathering systems and its needs as well as to determine if the Council for Scientific Research (CSIR) could contribute to the establishment and maintenance of such an NRTSD. This model requests road authorities and municipalities to conduct similar research in their respective cities to determine if there is a lack of data or a subpar level of data gathering, and to provide solutions to this through an NRTSD method (Mynhardt, 2013).

9. Barrier Line Management Model (BLMM)

   This model is a law enforcement model that is based on a quality control method developed to monitor and reduce traffic offenses by pedestrians, non-motorised transport (NMT) units, public transport drivers and personal vehicle drivers. This model provides insight and recommendations on how traffic authorities can go about enforcing the law in a scientific manner (Mohlala, 2015).

2.5 Other characteristics of TMCs

The operating expenses of TMCs are expensive and management of a TMC is quite demanding. Funding can limit deployment at TMCs. The effectiveness of TMCs is also limited due to municipalities being reluctant on handing over certain tasks, such as signal timing. Questions have also arisen regarding the ownership of, rightful purposes for use, charges for, and storage parameters for data collected by TMC sensors and CCTV cameras (Mobility Investment Priorities, 2012).

2.5.1 Responsibility

The responsibility for implementing a TMC depends on its structure and the agencies involved. Generally one agency in a large urban area will take the lead and work with local and regional partners that may include metropolitan planning organizations (MPOs), cities, counties, transit providers, and emergency responders. (Texas Department ofTransportation, 2018).

2.5.2 Cost

The costs involved with creating a specialised facility to house a TMC vary dramatically with respect to:

(i) The size and scope of the operations to be managed by the TMC
(ii) Various construction issues, such as converting a building into the appropriate location for a TMC
(iii) Other factors such as regional labour and material costs

Table 2-1 shows the annual operation cost estimates for 2005 for the Houston TMC, USA.

Table 2-1: Estimated costs associated with the construction of a TMC (Mobility Investment Priorities, 2012)

TMC size *Operations/Days*	**Personnel** *Unit of cost ($1000s)*	**Physical plant** *Unit of cost ($1000s)*	**Total annual operation** *Unit of cost ($1000s)*
Large Regional TMC *24 Hours/Day, 7 Days/Week*	$1,278.1	$1,838.8	$3,116.9
Large TMC-Weekday *12 Hours/Day, 5 Days/Week*	$476.5	$180.7	$657.2
Medium TMC-Peak Period *8 Hours/Day, 5 Days/Week*	$277.9	$109.4	$387.3
Small TMC *Special events or incident response only*	$53.6	$46.9	$100.5

As it can be seen from Table 2-1, the cost to construct, operate and maintain a TMC is high, with costs estimated at over $3million for annual operation of a large regional TMC.

2.5.3 Project timeframe

Planning for the construction and operation of a large, multijurisdictional TMC takes a period of years to complete. Assessing operational and funding needs, assembling agency and private partners, and identifying the proper location and facility type are all required before moving toward actual construction. Small, single jurisdiction TMCs or those active during special events can be completed more quickly, but still take more than one year to integrate instrumentation and information to be managed from a single site and to secure required funding (Mobility Investment Priorities, 2012).

2.5.4 Other factors affecting TMC productivity

<u>Human error</u>

People are not immune to making mistakes. Fatigue comes into play when one monitors a certain section of the road network and might easily miss something important. Also, with the current traffic management processes in place, it is possible that a mishap could occur at some point of management or plan execution (Nowakowski, et al., 1999). There is also a possibility of increases in costs as human error increases.

Maintenance

With the current method of highway and traffic surveillance in place, which are cameras on highways, the maintenance requirement for this setup is relatively expensive and time consuming. These cameras are exposed to vandalism and theft. These cameras also do not provide a full-rounded view of the surroundings so there are areas that are 'left in the dark' (Mobility Investment Priorities, 2012). Personnel needs to be deployed to sort out any issues with these cameras which increase the effort required to maintain the current components of TMCs as well as increasing the cost to maintain these cameras (Texas Department ofTransportation, 2018).

Management

Managing a TMC and the processes that go with it is no easy task. Managing the amount of people and various different responsibilities they have causes management to be slow and sometimes ineffective. Less people will be required if drones were used since each drone will cover a larger area. Employees could then be tasked with monitoring different aspects that are associated with the drones' flight, implementation, data acquisition and data processing which will in turn provide a more effective management of traffic (Mobility Investment Priorities, 2012).

2.6 The benefits of using ITS in traffic management

The overall goal of any Intelligent Transport System (ITS) is to improve transportation systems on the road network while simultaneously reducing the detrimental impacts of transportation systems through application of technology. Along with promoting sustainable transportation programs such as a modal shift from public transport to other non-motorised transport modes, sum up a core characteristic of ITS (Saikar, et al., 2017).

Following the research of *Sustainable Urban Transport (India)*, there are six characteristically beneficial sectors of ITS, which are safety, mobility, productivity, energy and environment, efficiency and customer satisfaction. For these benefits, each one has a typical measurement to describe its benefit to the transportation industry (Sustainable Urban Transport Project (India), 2018).

Expanding on these benefits that ITS has on the transportation industry, a few examples of technologies associated with the TMCs that aid the ITS benefits are provided. Table 2-2 describes this in more detail.

Table 2-2: Benefits of ITS and measurement thereof (Sustainable Urban Transport Project (India), 2018)

Type of Benefits	Measurement/Description of how benefit is measured	Examples of technologies related to TMC that affect the measurement of the benefit
Safety	Changes in measures such as crash rates, traffic conflicts or traffic law violations.	• Variable Message Signs (VMSs) • Speed and Right of Way Warnings • Speed Enforcement • Traffic Signal Enforcement • Work Zone Management • Variable Speed Limits • Road Weather Information and Management
Mobility	Reduction of travel time and delay and on-time performance.	• VMSs • Adaptive Signal Controls • Surveillance • Automatic Vehicle Locating • Computer-aided Dispatch Systems • Transit Signal Priority • Advanced Signal Systems
Productivity	Cost saving to transportation providers, travellers or shippers.	• Automatic Vehicle Locating • VMSs • Road Weather Information and Management, as well as Winter Management Strategies • Patrolling Services dispatched from the TMC
Energy and Environment	Fuel savings and reduced pollutant emissions.	• Advanced Signal Systems • Service Patrols • Electronic Toll Collection (such as e-tolls in Gauteng) • Roadway surveillance • Speed Control and Congestion Pricing
Efficiency	Transportation systems ability to manage and accommodate additional capacity demand and an increasing Level of Service (LOS).	• VMSs • Advanced Signal Systems • Adaptive Signal Controls • Work Zone Management • Automatic Vehicle Locating
Customer Satisfaction	Amount of travel across various modes of transport, mode choices and quality of service as well as volume of complaints or compliments received.	This section falls across the other five sections of ITS benefits.

Following the study *Intelligent Transportation Systems Benefits, Costs, Deployment and Lessons Learned (2011)* conducted by the US Department of Transportation, the benefits that ITS has to Arterial Management Systems (AMSs), Freeway Management Systems (FMSs), Transit Management Systems and Traveller Information Systems are in abundance. An extensive insight into the benefits of ITS to a large number of fields within Transportation Engineering were assessed, such as traffic control with the use of adaptive signal control, bicycle and pedestrian traffic control, lane and parking management, road weather management, emergency management and more. A positive result is shown relating to the ability of the aforementioned systems to achieve their goals and the costs of these systems were reduced when ITS was implemented.

In addition to this, research in Incident Management Systems, Freight Management Systems, Emergency Management Systems and Information Management provides a holistic view of how ITS affects the transportation industry and conventional form of traffic management. The measurement of the benefits for these systems were based on a study conducted at Portland State University in 2005, which assessed the difference in volumetric and other traffic related data before and after the introduction of ITS in TMCs in the states of Oregon and Virginia (Bertini, et al., 2005). Following this study:

- With the implementation of advanced control systems and disseminating traveller information, AMSs could potentially reduce delays within a range of 5 – 40%.
- FMSs could reduce the number and frequency of accidents by up to 40%, as well as decrease overall travel times by 60% and improve freeway capacity.
- The duration of incidents on the roadway could be reduced by 40% with ITS integrated to the Incident Management System (IMS). Other benefits such as increased public support are also obtained.
- Management of freight systems could provide a 35% reduction in cost to motor carriers by implementing commercial vehicle information networks.
- Transit management systems could potentially reduce transit travel time by 50% and increase reliability by 35% with automatic vehicle location technology and implementing transit signal priority.

2.6.1 Components of Arterial and Freeway Management Systems

AMSs and FMSs manage traffic by using traffic signal control systems, CCTV cameras, ramp meters, VMSs and system detectors to improve the efficiency of the road network. The purpose of AMs and FMSs are to use the information provided by users and data collectors to improve the flow of traffic, improve traveller experience and increase safety by reducing incident occurrences and shortening the time for Emergency Management Systems (EMSs) to respond.

2.6.1a) Road classification for FMSs and AMSs

There are three road classes for urban roads: U1, U2 and U3, and three for rural roads: R1, R2 and R3. U1 and U2 roads are principal arterials where 40 – 65% of the veh-kms are served, where roads with class U1, U2 and U3 are principal + minor arterials where 65 – 80% of the veh-kms are served. A U1 class road is an urban principal arterial, U2 class road is an urban major arterial and a U3 class road is an urban minor arterial. For rural roads the percent of veh-kms served, road length and speed limits differ slightly as compared to the urban road classes as described in Table 2-3 (Committee of Transport Officials (COTO), 2012).

Table 2-3: Road class and description

Road class	TRH 26 description	Percent of vehicle-kilometres	Road length	General speed limit
U1	Urban principal arterials	40 – 65%	>20 km	100 km/h
U2	Urban major arterial	40 – 65%	At least 10 km	80 – 100 km/h
U3	Urban minor arterial	15%	≈ 2 km	60 – 80 km/h
R1	Rural principal arterial	30 – 55%	Up to 50 km	100 km/h
R2	Rural major arterial	30 – 55%	25 – 50 km	80 – 100 km/h
R3	Rural minor arterial	15 – 20%	10 – 100 km	60 – 80 km/h

2.6.1b) Adaptive Signal Control Systems

By continually adjusting signal timing parameters based on current traffic volumes, adaptive signal systems can coordinate and manage traffic efficiently on road networks. An advanced signal control system consists of centralised control of traffic signals and coordinated signal operations across neighbouring cities. The benefits include reductions in delay, travel time, vehicles stops and fuel emissions.

The extent of these benefits depends on how effective the system addresses the traffic situation. In the USA for example, Toronto's Split Cycle Offset Optimisation Techniques (SCOOT), which automatically adjusts the green time by detecting volumes of traffic approaching a signal from different directions to best match the requirements of the oncoming traffic, was found to reduce stops by 29% and vehicle delay by 26% in Toronto (Kelman & Greengough, 2017). Following this success, Toronto was able to expand their system to 250 intersections. The cost of the investment was covered with system benefits in just 2 years. In Oakland County, Michigan, use of the Sydney Coordinated Adaptive Traffic System (SCATS) resulted in a 9% decrease in travel time in the morning peak travel direction and 7% decrease in the evening peak travel direction (Abdel-Rahim, May 1998). The SCATS system in Florida reported a 28% decrease in the number of stops and a 33% reduction of stops was reported in Michigan (Abdel-Rahim, May 1998). In Virginia, the total annual emissions for Carbon Monoxide, VOC and NO_X decreased by 134,600 kg after implementing ITS methods of traffic management (Relch, 2019). Implementation of coordinated signal timing that communicates to a central computer system in 2004 has proven to have substantial benefits, with an 85% reduction in stops being reported. Along with this, the average user travel time was determined and it was reduced by 33% after the implementation of ITS systems, with road users saving an average of 85,000 gallons of fuel per year (DKS Associates, 2002).

2.6.1c) Monitoring and traffic surveillance

Traffic surveillance and monitoring has one overarching goal, which is to supply information about various traffic conditions to the appropriate parties so that suitable responses and control actions can be undertaken. Traffic surveillance includes the use of CCTV cameras, communication networks and system detectors. These tools help improve incident management, inform decision-making and determine traffic conditions for collected and processed information (Mobility Investment Priorities, 2012). By monitoring traffic in a controlled environment, traffic operations and planning can be enhanced by serving the following purposes:

- Detecting and verifying incidents that affect traffic operations.
- Monitoring of incident clearance.
- Monitoring traffic for special events and emergencies.
- Supporting the implementation of control strategies such as automated traffic signal coordinated systems (ATCS) and ramp metering.
- Monitoring the conditions of the pavement and the environment.
- Assessing of operations to generate data for research purposes. These datasets can lead to information regarding characteristics such as traffic flow rate, space occupancy and origin-destination (OD) flows (Bertini, et al., 2005).

Data regarding traffic conditions and incidents can be collected through various detector surveillance technologies such as:

- Magnetometers and inductive loop detectors which are embedded in the roadway.
- Vehicle probes from Floating Car Data (FCD) using Automated Vehicle Identification (AVI) and Automated Vehicle Location (AVL).
- Non-intrusive detectors such as radar, infrared and digital video imaging (Bertini, et al., 2005).

Detection systems such as CCTV reduce the time difference between the occurrence of an incident and the time it is detected by operators. A large city TMC, such as the TMC which monitors Cape Town's traffic, detects an incident approximately 3 minutes after it occurs (Birungi, 2019). Figure 2-4 shows a typical view from a CCTV camera. Figure 2-5 shows the operator workstation for a typical TMC in South Africa. Each operator monitors 32 cameras on two monitors, viewing 16 cameras per monitor.

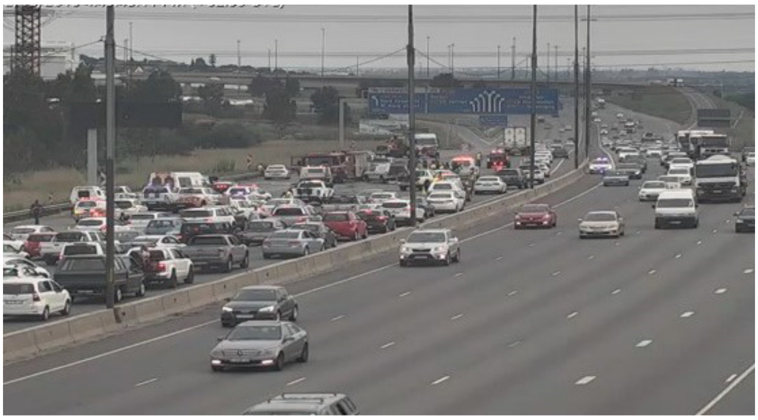

Figure 2-4: A typical view from a CCTV camera in a TMC (Birungi, 2019)

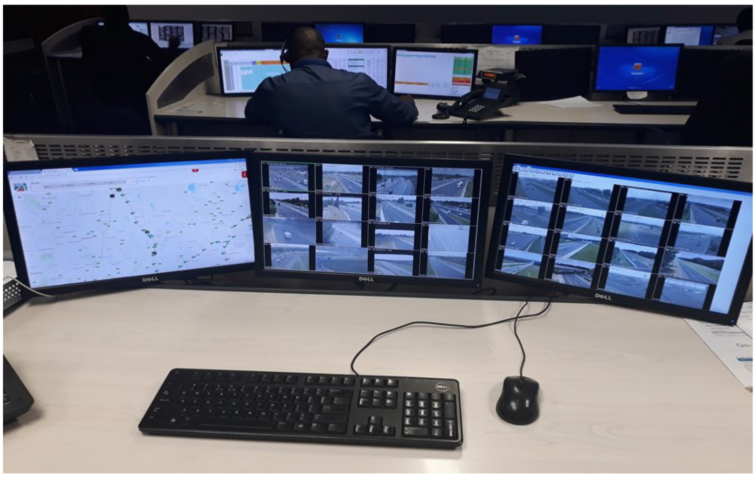

Figure 2-5: Operator's workstation (Birungi, 2019)

CCTV cameras help to determine the location of incidents as well as the incident's severity. CCTV can also provide digital video images to be used in video image processing algorithms to help automatically detect the occurrence of an incident. Using CCTV cameras can also reduce the verification time since all incidents needs to be verified before incident response vehicles and personnel can be dispatched (Bertini, et al., 2005).

Following the research of *Sensor Systems (2002)*, after comparing the situation on the road network in Buffalo, USA, before and after deployment of CCTV cameras, the following quantifiable benefits of detection and surveillance was found:

- Reduction of non-recurrent delay along the corridor.
- Reduction of vehicle emissions associated with delay reduction.
- Reduction of fuel consumption associated with delay reduction (University of Buffalo, 2017).

For San Antonio, the first phase of the *San Antonio TransGuide System* (SATGS) became operational in 1995. The system included lane control groups, loop detectors, 26 miles of freeway with VMSs equipped with surveillance cameras and a communications network. Incident statistics from August-December 1992, 1993 and 1994, before surveillance cameras were present, was compared to this same data for December 1995 after the deployment of surveillance cameras. (Bertini, et al., 2005). Significant improvements of safety were observed after the implementation of the *TransGuide System.* These improvements include a 35% reduction in total accidents with a 30% reduction in secondary accidents (accidents caused by a traffic queue) and a 40% reduction in accidents during stormy weather. Overall, a 41% reduction in the total accident rate (accidents per million vehicle-miles of travel) was observed (Henk, et al., 1996). After reviewing the video surveillance data, an average reduction in response time of 20% was found for the city of San Antonio. As a result of this reduced incident response time, it was estimated that an average delay of 700 vehicle hours and a reduction of 2,600 gallons of fuel per major incident were saved. Based upon the frequency of accidents on the freeway, the annual savings after the deployment of video surveillance was found to be $1.65 million (Henk, et al., 1996). Furthermore, after conducting fifteen before-and-after surveys containing input from over 600 downtown San Antonio employees regarding the video surveillance and message signs, the results of these surveys were found to be:

- An increase of 46% of people felt that the newer methods of traffic management and incident notifications were appropriate.
- Before the study, 58% of people used alternative routes during incidents and this statistic has improved to 71% after the study.

- After the study, 88% of *TransGuide System* users felt that the messages were very easy to understand (Henk, et al., 1996).

2.6.1d) Ramp metering

Ramp meters are a control measure to allow for an increase in efficiency and safety on freeways by preventing bottlenecks from forming. In its most basic form, ramp meters are traffic signals located at freeways on-ramps which assists in controlling the flow of vehicles onto the freeway (Mizuta, et al., October 2014). Based on a pre-determined or variable cycle length, vehicles are allowed to enter the freeway only when the signal is green. The cycle length for the ramp meters is based on the volumetric traffic conditions for the freeway. Figure 2-6 shows a basic diagram describing how ramp metering works. Vehicles travelling from an adjacent arterial onto the ramp create a queue behind the stop line. Upon a green signal, vehicles are released individually onto the main highway concurrent with a rate dependant on the traffic volume and speed on the highway at that time (Mizuta, et al., October 2014). Not only does this allow for efficient traffic control and aid in reduction of congestion, but can also be used in the event of an incident to re-route or halt the traffic flow until the incident is cleared.

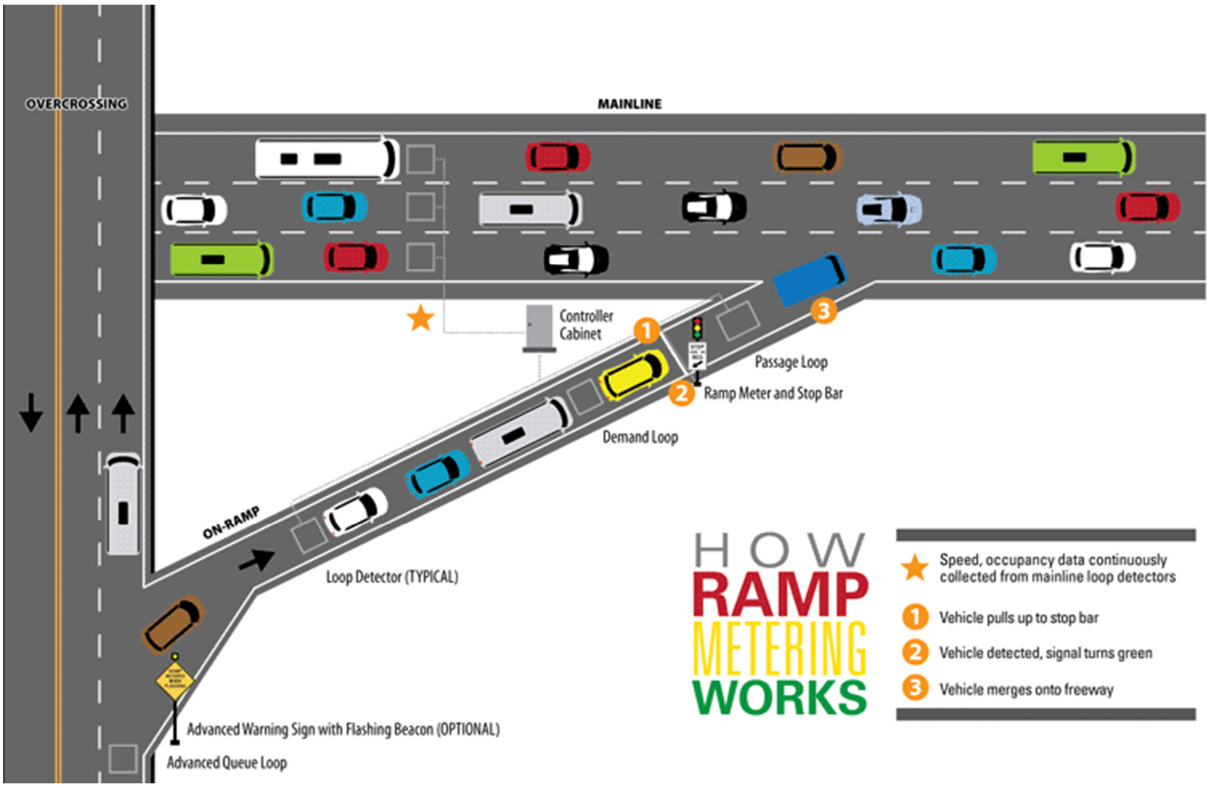

Figure 2-6: Configuration of ramp metering (Parsons Brinckerhoff, n.d.)

2.6.1e) Urban Traffic Management (UTM)

UTM is a general term to describe the components required for efficient management of urban traffic. UTM systems require traffic signals, Variable Message Signs (VMSs), signal controllers and ramp meters to control traffic. UTM is a subset of Arterial Management since it employs similar systems as an AMS. UTM systems also require:

- A communications network for the transfer of traffic data to equipment components.
- Data communication between different components.
- Algorithms that use current traffic data to predict future traffic loads and support decisions on optimal traffic and network control measures by minimising delay and congestion.

(PIARC, 2018).

2.6.2 Incident determination using Floating Car Data (FCD)

Research into the determination of an incident using FCD has been an increasingly evident topic on ITS. Efficiently using FCD can yield many benefits to transport planners and traffic management agencies. One benefit that stands out for the purpose of this study is the use of FCD to detect an incident accurately.

Houbraken et al (2017) compares the incident detection capability of a traditional automated incident detection (AID) system which consists of communication between loop sensors and Variable Message Signs (VMSs), to an AID system created from data obtained from a sample of vehicle probes representing 6% of the country-wide traffic in the study area. Two highways in Holland were assessed which both had the traditional AID systems in place. The goal of the research conducted by Houbraken et al (2017) was to improve the efficiency of incident detection and to determine the delay introduced with FCD. The traditional system works as follows: Traffic loop sensors that are spaced approximately 500 m apart communicate with VMSs. Each loop sensor records the speed of the vehicle driving over it. When the speeds of vehicles drop suddenly to a value below a predetermined speed, this indicates that an incident has occurred, which prompts the appropriate VMS to indicate to drivers what to expect and how to alter their route (Houbraken, et al., 2017). When vehicle speeds increase above the predetermined speed, VMSs are turned off since the incident has been cleared.

Following this, the traditional system is extended with the use of FCD. The traditional system is limited by input (loop sensor) data which is only available on a quarter of all Dutch highways. FCD consists of singular vehicle samples generated by tracked probe vehicles. Each sample consists of a pair of coordinates, a vehicle identifier, vehicle heading and speed and a timestamp. This provides for a finer granularity in results as opposed to the traditional system with loops every 500 metres. Samples are generated every 10 seconds and sent to a central server for processing. Erroneous data such as vehicles outside the study area and inconsistent data are filtered out. At the central server, virtual "loops" are placed every 50 metres which assesses the speed of vehicles. If vehicle speeds drop below a predetermined value for congestion, VMSs are activated to indicate to drivers that an incident has occurred.

Houbraken et al (2017) assessed the FCD system against the traditional system that was in place by comparing delay results. Since the FCD consists of more steps, an average delay of 30 seconds was determined (if vehicles transmitted data once every minute) caused by data collection, processing and transmission. This was found to be larger than the delay caused by traditional system (value not provided). Since only a sample of vehicles are assessed, extra sampling further increased delay. Further research shows that incidents with a duration of at least 20 minutes can be recognised with a probability of 65% if 1.5% of the vehicles on a road network are used as probes for FCD that send two incident messages per event (Kerner, et al., 2005). The benefits of an FCD system, however, is that it is cheaper since minimum hardware is required on highways and that a larger sample area can be covered (Houbraken, et al., 2017).

2.7 TMCs and traffic conditions around the world

In order to obtain a greater understanding of how TMCs operate and the functionality that goes with TMCs, an analysis of TMCs in other countries should be conducted. Not only does this broaden the knowledge of TMC operations and how these are carried out, but understanding how different countries deal with traffic incidents and issues characteristic to specific countries is useful when creating a TMC that caters for many different user needs, such as in Stellenbosch.

Cities around the world have their own ways of dealing with congestion in traffic. Whether it is by introducing levy fees or by improving public transport, traffic management of cities around the world recognise the inconvenience and negative impacts that congestion causes. Some examples of how cities deal with traffic congestions are listed, along with the average speed during the morning peak hour and total number of cars on the road network. The statistics provided were last updated in December 2014. Data provided by Mukherjee, 2014 (Mukherjee, 2014).

- Singapore - Average speed of 28.5 km/h, 0.9 million (mn) total vehicles. The city follows a vehicle quota system whereby a person buying a new car pays up to 140% in taxes. There are also levied congestion charges on certain roads.

- Moscow – Average speed of 15.6 km/h, 5.5 mn total vehicles. Congestion in the Russian capital increases the average trip length by 66% during peak hours. Road management in Moscow has seen the number of parking lots being increased and public transport and road construction being improved, but this only resulted in an 8% reduction in average trip length during peak hours.
- Bangkok – Average speed of 15.7 km/h, 8.55 mn total vehicles. Downtown Bangkok has a roadway designed to accommodate 2 million vehicles. As of 2007, the reported number of vehicles on the roads in downtown Bangkok is 5 million. The introduction of skyways, expressways, a 23 km transit system and various flyovers has seen a reduction in traffic congestion of 40%.
- Rio de Janeiro – Average speed of 20 km/h, 5.2 mn total vehicles. Certain parts of Rio are auto-free zones and the introduction of an even-odd license plate system, where road access in based on the last digit of your license plate, has caused a drastic reduction in congestion in the city.
- London – Average speed of 19 km/h, 2.6 mn total vehicles. London has a daily congestion fee of £11.50 and Greater London is a low-emission zone, which encourages diesel vehicles to be maintained and vehicles not complying to this are not allowed to be driven.

Two countries and their respective methods for managing traffic have been analysed. The two countries chosen provide a broader understanding of traffic management since these countries each have different traffic conditions and management strategies. The steps these two countries have taken in order to improve road efficiency provides experience in solving traffic issues. Furthermore, an assessment of how the TMC in Cape Town operates is also provided.

2.7.1 India – New Delhi

The traffic situation in most Indian cities is critical, with overpopulation and improper road management being two key factors leading to the overly congested roads. As of 2017, the population of India is 1.339 billion and increasing (Worldometers, 2019). Other than this, the problems in Indian cities causing management issues are:

- There are simply not enough roads to keep up with the increasing number of cars being introduced to Indian roads.
- There is a lack of walkways or footpaths for pedestrians in most cities.
- Bad town planning has led to acute shortages of parking spaces in cities.
- Traffic congestion has led to an increase in the number of accidents on the road. Delhi has the third highest accident rate in the world.

- Inadequate/Inefficient public transport adds to congestion in cities instead of relieving congestion.
- Low average driving speeds due to congestion is present in large cities, which increases travel delay (Pendakur, 2007).

Transport in Delhi is maintained by the New Delhi Municipal Council (NDMC), Municipal Corporation of Delhi (MCD), Delhi Cantonment Board (DCB), Public Works Department (PWD) and Delhi Development Authority (DDA) (New Delhi Municipal Council, 2008). The road length in Delhi has increased at a rate of 4.5% per year, which is not in line with the growing population. The timing of signalised intersections ranges between 120 – 180 seconds which causes long queues especially in the morning and afternoon peak hours. The traffic in Delhi consists of various modes of transport which include buses, trucks, animal-driven carts, two and three wheelers and personal vehicles. This mixture of different modes of transport produces its own set of traffic issues since the infrastructure is inadequate to maintain all these different types of vehicles (Saikar, et al., 2017).

2.7.2 Virginia, Washington DC

The state of Virginia in the USA has a population of 8.5 million people, with 7.5 million vehicles registered in the state (Worldometers, 2019). This means that around 88% of the population of Virginia owns vehicles. Although it being the 35th largest state in the USA, this area experiences its own problems with regards to traffic conditions. Northern Virginia is home to a few of the worst traffic bottlenecks in the country, with a queue length of 1.1 miles occurring, resulting in an annual total delay of 1,100,000 hours and an annual lost value of time equalling $27 million (Forzato, 2015). Although these values seem quite low relative to other cities of other countries and even other cities in the USA, traffic still needs to be managed here so that the situation does not deteriorate. This is done through the Virginian Department of Transportation’s (VDOT) Traffic Operations Centre (TOC).

The VDOT’s TOC opened in 2008 and operates for Northern Virginia, Washington DC. It costed the state around $127 million for the TOC to be constructed. The TOC takes up 10,600 square metres of space, with the operations floor being 1,120 square metres in size, the special investigative area and Emergency Management Centre being 3,650 square metres and 335 square metres in size, respectively. The TOC is staffed 24 hours a day, 7 days a week for every day of the year, with shifts ranging between 6 – 8 hours per day. There are three operator workstations dedicated to interstate freeway sections, two call-taker workstations and an enclosed work area for supervisors (Sustainable Urban Transport Project (India), 2018).

2.8 Cape Town's TMC

Cape Town's TMC was a 2010 FIFA World Cup legacy project and was opened in 2010 and had a total implementation cost of R160 million. The TMC brings together services such as urban traffic control, freeway management, transport information gathering and processing, integrated public transport management and Emergency Management Services (EMS) together in one operation environment designed to provide efficiency in traffic and alleviate or lessen congestion (hi-tech security, 2013). The TMC is situated in Goodwood and facilitates the management of traffic incidents and emergencies and provides road users with up to date information that allows them to select the best route to take to arrive at their destination. Figure 2-7 indicates the TMC.

Figure 2-7: Cape Town's TMC situated in Goodwood (hi-tech security, 2013)

TMSs at the TMC include:

i) **Freeway Management System**

The effects of extreme traffic congestion, such as reduced productivity in the road network, an increase in the running cost of vehicles, and environmental degradation are evident and the City of Cape Town notices these effects and uses the TMC to improve the flow of traffic and deal with accidents efficiently.

The system uses 197 CCTV cameras to monitor the traffic flow and 48 variable message signs to communicate with road users.

ii) **Arterial Management System**

The arterial management system comprises traffic signal controls with CCTV cameras. Traffic signals play a vital role in keeping traffic in the city moving smoothly. The TMC is also home to the traffic signal fault reporting and management section.

iii) **Integrated Incident Management**

A key component of the TMC is to improve the current incident management system, which will result in faster emergency and incident response. The TMC does this by enhancing the lines of communication and the speed and efficiency of the notification between the location of the incident and the incident management system.

The video wall system consists of the following:

- 48 46-inch LCD screens.
- 1 high-end graphics controller for the visualisation of video and data signals.
- 1 wall management software package (hi-tech security, 2013).

2.8.1 The integrated service of Syntell's Road Management Service to the City of Cape Town

With more than 25 years of experience in the development of road TMSs, Syntell is one of the leading developers in traffic management and has partnered with Metros and local authorities across South Africa to provide innovative solutions to traffic-related issues. The Syntell Remote Management Service (RMS) is a cost effective traffic management tool, designed for the transport authorities. The system communicates with the traffic controller on the street to provide remote monitoring of traffic flow and other traffic-related data to aid in the alleviation of traffic congestion and to provide faster emergency response (Syntell, 2014). Figure 2-8 shows the RMS office at Syntell's Cape Town branch, with another one being situated in Midrand.

Figure 2-8: Syntell's RMS office for Cape Town (Syntell, 2014)

Syntell's RMS is a system that allows for monitoring and control by means of manual intervention. The intelligence is retained at the on-street controller and is not dependent on the communication line to operate. In the event of communications failure the controller will rely on its own on-board clock to provide synchronization.

2.9 The role and function of the South African Road Traffic Management Corporation

The Road Traffic Management Corporation (RTMC) was established in terms of Section 3 of the RTMC Act, 1999 and commenced with the preparation of Business and Strategy Plans for its operationalisation in April 2005 (RTMC of the Department of Transport, 2013). The RMTC operates closely with the Department of Transport which produces an effective partnership between national, provincial and local spheres of government in the management of road traffic incidents (Ismail & Venter, 2007).

2.9.1 Roles of the Department of Transport and the RTMC in transport management

The RTMC was established in 1998 in accordance with the RTMC Act (Act 20 of 1998) to ensure efficient traffic safety and road usage through:

- Coordinating provinces, local municipalities and metros
- Keeping records of all accidents in the country
- Training of traffic personnel
- Promoting traffic safety throughout the country (Mohlala, 2015)

The role of the DoT is the provision of safe road infrastructure through the RTMC, SANRAL, the provincial Departments of Transport, the metros and local municipalities. Figure 2-9 indicates the role of the DoT and the RTMC in the implementation process and management plan for a TMS, as explained by Mohlala (2015).

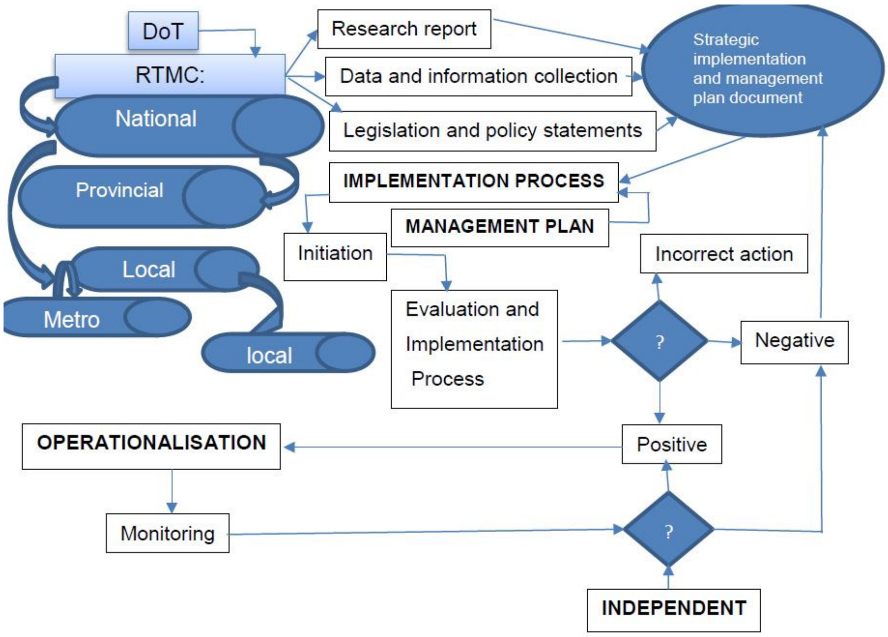

Figure 2-9: The role of the RTMC and DoT in management of a TMS (Mohlala, 2015)

Figure 2-9 demonstrates the RTMC as the agency of the DoT. In this regard, the role of DoT is to provide safe road infrastructure through SANRAL and to develop a National Road Safety Strategy (NRSS) to provide road safety policy and strategy direction to the RTMC (Mohlala, 2015). The role of the RTMC is to coordinate road traffic issues at national level, provincial and local levels (metro and local municipalities). It also has the duty to develop a strategic implementation and management plan. In relation to this, in 2015 the RTMC developed the Strategic Plan (2015-2020) and Annual Performance Plan (2016–2017). The DoT developed the National Road Safety Strategy, 2016 – 2030 (NRSS) in line with the National Development Plan (NDP) that is to direct the RTMC strategy**.** The DoT realised that without a special effort, it will not achieve the 50% reduction of road traffic fatalities in the year 2020, in line with the UN DoA (Mohlala, 2015).

2.9.2 Purpose of the RTMC

The development, safety and quality of life of South African citizens and regulations pertaining to these aspects were recognised the RTMC was therefore established for the following reasons:

- To enhance the overall quality and efficiency of road traffic management and services.
- To maximise the effectiveness of local and provincial government efforts with special attention to road traffic law enforcement.
- To guide and maintain the expansion of private sector investment in road traffic management (Ismail & Venter, 2007).

2.9.3 Functions of the RTMC

There are different role-players who work together to allow for the improvement of road traffic efficiency throughout the country. These different role-players are:

- Office of the Chief Executive Officer
- Corporate Support Service
- Chief Financial Officer
- Functional Unit – Information Systems
- Functional Unit – Road Traffic Marketing and Education
- Functional Unit – Enforcement Coordination
- Functional Unit – Research and Development (Ismail & Venter, 2007)

2.10 The use of UAVs in traffic management

The Unmanned Aerial Vehicle (UAVs) commonly known as drones are considered as one of the most dynamic and multi-dimensional emerging technologies of the modern era. Recently, this technology has found multiple applications in the transportation field as well; ranging from the traffic surveillance applications to the traffic network analysis for the overall improvement of the traffic flow and safety conditions (Khan, et al., 2017). However, in order to conduct a UAV-based traffic study, an extremely diligent planning and execution is required followed by an optimal data analysis and interpretation procedure. This paper presents a universal guiding framework for ensuring a safe and efficient execution of a UAV-based study. It also explores the analysis steps that follow the execution of a drone flight. The framework based on the existing studies, is classified into the following six components:

(i) scope definition
(ii) flight planning
(iii) flight implementation
(iv) data acquisition
(v) data processing and analysis
(vi) data interpretation (Khan, et al., 2017)

The proposed framework provides a comprehensive guideline for an efficient conduction and completion of a drone-based traffic study. It gives an overview of the management in the context of the hardware and the software entities involved in the process. In this paper, an extensive yet systematic review of existing traffic-related UAV studies is presented by moulding them in a step-by-step framework. With the significant increase in the number of UAV studies expected in the coming years, this literature review could become a useful resource for future researchers. The future research will mainly focus on the practical applications of the proposed guiding framework of the UAV-based traffic monitoring and analysis study (Khan, et al., 2017).

With the increasing amount of vehicles traveling on road networks, new methods to obtain useful traffic data has to be formulated constantly. Most data collection methods require a large fixed infrastructure and some methods are labour intensive (Mobility Investment Priorities, 2012). Over the years, traffic data collection methods have evolved with the advancement in technology. Induction loops, overhead radar sensors and fixed video camera systems have been used in monitoring the status of traffic for many years (de Souza, et al., 2017). Although these methods provide accurate data, this data is only measured over a particular point with little to no useful data about traffic flows over space being obtained. This then means that a number of hidden points with a high density of traffic is unmonitored and cannot be assessed and the true cause of certain traffic congestions are sometimes not determined. Manual detections are then required by specially deployed personnel to deal with traffic issues. This process, although effective, is quite tedious and time consuming and there is much room for improvement. Other advances in traffic data collection include advanced ITS technologies such as probe vehicles with GPS and FCD although these are not accurate at times since drivers know they are being monitored (Khan, et al., 2017).

Recently, complex traffic situations were observed with non-intrusive sensors and cameras mounted on airborne systems. Manned aircrafts were used for traffic surveillance purposes, but a number of quality, cost and safety issues and proven these methods to be inefficient. As such, unmanned aerials systems in the traffic monitoring, management and control have started to become more desirable.

The Unmanned Aerial Vehicles (UAVs), also known as drones, are considered to be one of the most multi-dimensional and dynamic technologies of the modern era. UAVs are being used in various situations, from commercial tasks such as sports coverage, surveillance and parcel delivery to research applications such as surveying of inaccessible areas. UAVs are also used in the transportation field to monitor the traffic flow. UAVs cover a large area in a shorter amount of time with significantly lower cost (cameras not needed every few kilometres). UAVs equipment is also reusable to a different point of interest.

The use of drone technology does require a high level of precision with regards to planning and management, however. Governmental laws would be required and alterations to current laws would be needed to implement the use of drones in traffic management. Mismanaged execution of UAV flight could be severely detrimental and it will interfere with the processes of other aerial vehicles, such as aeroplanes and helicopters.

2.10.1 Framework

As proposed by Khan et al (2017), the steps needed to ensure successful, efficient and safe implementation of UAVs in an existing traffic network, is as follows:

2.10.1a) Defining the scope

The definition of the scope is a critical step in any project as all the following steps are dependent on it. The problem statement has to be clear and fixed project objectives must be defined during the definition of the scope. Here, all aspects related to drone flight and software implementation should be clearly stated.

2.10.1b) Flight planning stage

The flight planning stage involves the preparation for the implementation of the actual UAV flight for the collection of the required data. Since the number of UAVs has increased dramatically over the past few years, governmental laws are now required to avoid major mishaps. These laws are stated in Section 2.10.3, which gives an overview of South Africa's RPAS (remotely piloted aircraft systems) regulations. As such, the UAV flight planning stage has become even more important. UAV flight planning can be categorised into three main categories which are safety, environment and route planning, as indicated in Figure 2-10.

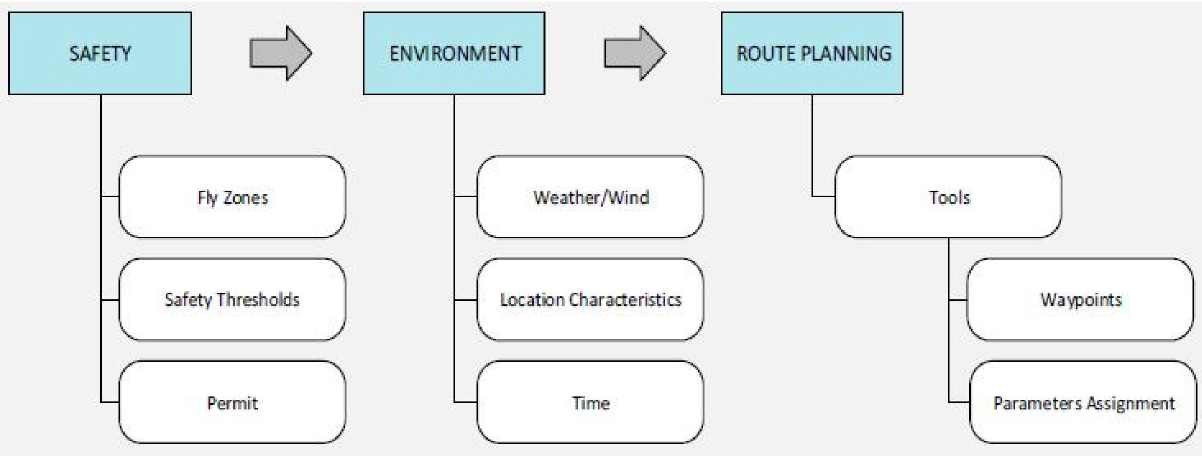

Figure 2-10: Components of flight planning stage (Khan, et al., 2017)

With reference to Figure 2-10:

1. Safety

   Firstly, the flying zones must be determined and evaluated with the aid of local flying zone maps. The distance between the drone and active air fields needs to be adequate enough to ensure that the drone does not interfere with other sensitive instalments. Once the safety zone(s) are determined, project characteristics and other safety thresholds such as flight parameters, have to be determined to ensure that sufficient measures are in place to ensure safety while the drone operates. Finally, flight permits and proper authorisation needs to be acquired and the relevant authorities must be notified of the proposed UAV activity.
2. Environment

   Location characteristics such as infrastructural environment and extents of the built-up area in the study zone must be considered to produce optimal flight parameters. Attention should be brought to the weather and wind conditions in the area and the time of day that the drone flies should be chosen wisely. For example, UAV flights and surveillance checks could be conducted midday so that shadows are minimal, which will produce higher quality imagery. Drones and the outer body of it should be designed to break strong winds that could be damaging.
3. Route planning

   In order to determine the route(s) where the drones will travel, appropriate route planning tools needs to be used. Once routes are decided on, waypoints should be marked along the desired path(s).

2.10.1c) Flight implementation stage

During this stage, the UAV flies over the study area following the planned route determined in the flight planning stage. The drone's flight is either manually controlled via a radio controller or automatically via the auto-pilot. The footage obtained by the drone has to be of high quality and have high resolution, and thus the camera should be stably built to avoid any wobbly or shaky footage. Minor stability issues are dealt with during the pre-processing stages. A gimbal can be used to allow a 3-axis rotation of the camera and allowing the camera to be aimed at will, unlike fixed cameras that cannot be rotated.

2.10.1d) Data acquisition

The data that has to be acquired from the drone includes the high quality video recording of the study region along with data from thermal, infrared and other sensors. Data describing speed and positioning of the drone may also need to be acquired to calibrate the video footage. The data can be acquired offline or in real-time depending on the requirements of the project. Offline acquisition is when the video from the drone is acquired and processed after the completion of the drone's flight. Real-time data acquisition sees the drone transmitting live to the ground station where a near real-time image processing procedure occurs followed by a statistical analysis for vehicle risk modelling.

2.10.1e) Data processing and analysis

The processing and analysing of data can be done in many ways and are generally classified in two ways; semi-automated and automated video analysis.

Semi-automated video analysis ensures a high level of accuracy and reliability and is easy to set up. No complex image processing algorithms are required therefore more manpower is required since ground control points must be established.

Automated video analysis of a UAV's traffic data consists of a series of advanced image processing techniques and requires minimal manpower. There are some limitations, however, such as varying accuracy due to light and climatic conditions. Also, an automated system requires high computational power and is difficult to initially set up since it involves complex algorithms.

For both approaches, the procedure remains somewhat similar and can be summarised in the following four steps:

(i) Pre-processing: Trimming of the video and image rectification
(ii) Stabilisation: Filtering the video footage
(iii) Calibration: Achieved through the use of GIS and coordinate systems
(iv) Object tracking: Semi-automated or automated

2.10.1f) Data interpretation

Data interpretation is done with the aid of various types of graphs that are created as an output of the data analysis procedures. The trajectories of vehicles in the road network are displayed in x-y planar graphs to help understand the behaviour of the road users. Such trajectories are also represented to illustrate the traffic movement across the segment of the road/area surveyed.

2.10.2 Challenges with UAVs in traffic management

Challenges that hinder the swift implementation of UAVs in traffic management, as defined by Ganjoo, 2018, are:

- Defining technology protocols to aid interactions and data exchange between UAVs and traffic management services

- Determining acceptable key performance measures (KPIs) for latency and reliability of UAV systems
- Managing the secure exchange of data and access to data associated with UAVs
- Licensing regulations and the difficulty and complexity of introducing UAVs to urban and arterial traffic management
- Limited UAV battery life and varying sight distance, flight heights and camera quality.

(Ganjoo, 2018).

2.10.3 An overview of South African RPAS regulations

The use of remotely piloted aircraft systems (RPAS, or “drones) has grown significantly over the past 25 years since its earliest appearance at South Africa’s first democratic election in 1994 where it was used by the South African military for surveillance of areas where possible violent protests were expected (Kock, 2015). In South Africa, the RPAS industry has grown and a use for these systems to assess the country’s socio-economic challenges were observed. As such, urgent legislation was needed to regulate the industry to ensure safe operations of RPAS and these laws were put together by The South African Civil Aviation Authority (SACAA). These laws, which were created by SACAA with the aid of various industry stakeholders, came into effect on 1 July 2015 (Kock, 2015).

2.10.3a) Types of operations

With the addition of the SACAA laws to the aviation industry, additional operations were added to the rules and regulations stated by SACAA in order for an RPAS pilot to be eligible to fly a drone.

A summary of the regulations are stated below:

- An unregistered RPAS can only be used for private purposes and not for commercial purposes.
- The person controlling the unregistered RPAS must adhere to the laws of the area/airspace they are present in.
- Any RPAS, registered or not, must be flown in such a way that it does not pose a risk of causing injury to people or damage to property.
- The RPAS must not be flown closer than 50 meters to any group of people, public roads or onto, from or over any private property without the owner’s permission.
- The RPAS should not be flown:
  - In prohibited or controlled airspace.
  - 10 km or closer to registered airfields or helipads.
  - Weighing more than 7 kg.

    - While intoxicated.
    - Higher than 150 ft (46 m) from the ground, except on a SAMAA registered field, where up to 400 ft is allowed.
    - Less than 300 m away from obstacles taller than 150 ft.
    - At night.
    - Over public roads.
    - Model aircrafts should not be flown for commercial purposes.
- The RPAS must be flown at a visual line of sight (VLOS) at all times only during daytime with clear weather conditions.
- The RPAS must not be flown further than 500 m away from the pilot.
- The RPAS must be inspected before each flight (Stopforth, 2017).

2.10.3b) Licensing

In order to obtain an RPAS license to be a registered RPAS pilot, a theoretical course and a practical assessment needs to be taken. The theoretical course consists of nine sections with most of the content being similar to that of manned aircraft training since pilots need to be aware of these regulations should larger RPAS be flown in airspaces with manned aircraft. (South African Civil Aviation Authority, 2015).

Theoretical course

A summary of the nine sections in the theoretical course is as follows:

- Navigation: This section is critical to develop the pilot's understanding of aeronautical maps and location of different airspaces.
- Principles of Flight: Basic aerodynamics are covered in this section and flight techniques needed at a practical level are taught here, including ascending and descending, what to do when the RPAS stalls and how to recover a drone if control is lost unexpectedly while being flown.
- Radio Telephony: This section of the course teaches the skills required by a pilot to communicate via radio effectively. Different classes of airspace, filing of flight plans and search and rescue procedures are also taught here.
- Human factors: Factors influencing vision, stress and fatigue of the pilot and how to deal with these are covered here.

- Meteorology: Here, the influence that different climate conditions have on flying is taught, such as the effect it has on the terrain being flown over, prediction of weather and vision capabilities.
- Operational Procedures: Administrative-based knowledge is provided in this section of the course, such as reporting with flight folios, log and data recordings, logging maintenance, emergency procedures and security and ground checks. All the fundamentals for the safe operation of an RPAS are taught here.
- Flight Performance and Planning: Here, characteristics of aerodromes are given, and various calculations important to the flight of an RPAS are taught, such as mass balance, fuel-weight and flight time calculations.
- RPAS General: Mechanical content relating to the RPAS are discussed here, such as aircraft propulsion, battery usage, components that make up an RPAS, radio controllers and data links and how different flight surfaces are controlled.
- RPAS CARs (Civil Aviation Regulations) and CATS (Civil Aviation Technical Standards) 101: Here, aviation law and regulations are covered, with special attention to safety-related aspects (Stopforth, 2017).

Practical assessment

After passing the theoretical assessment, the candidate has 90 days to complete the practical assessment. The practical assessment includes a medical examination similar to that which a manned-aircraft pilot goes through (Kock, 2015). Following this, an evaluation flight is performed which assesses a combination of all the exercises taught previously in the assessment. Once this assessment is passed, the instructor provides the candidate with a letter of recommendation required by the designated flight examiner (DFE) so that the candidate can perform a skills test (Stopforth, 2017). The skills test assesses different tasks and provides ratings on four different factors; overall ratings, aeroplane rating, helicopter rating and multi-rotor rating. These four ratings assess all the factors taught in the prior assessments and, if passed, a license is presented to the candidate. Table 2-4 provides a summary of the required certificates and licenses relating to RPAS operations for different flight intentions, including commercial, corporate and non-profit.

Table 2-4: Summary of required certification and licensing for RPAS operations (AviComply, 2015)

	Commercial	Corporate	Non-Profit
Air Service License (ASL)	X	-	-
RPAS Operator Certificate (ROC)	X	X	X
RPA Letter of Approval (RLA)	X	X	X
RPA Certificate of Registration (CoR)	X	X	X
Remote Pilot License (RPL)	X	X	X

2.10.4 Existing systems and current research work in UAV traffic management

2.10.4.1 Elloumi et al

The use of UAVs for traffic management is not a new concept, although it is fairly early in being implemented around the world. Research has been conducted in using UAVs for monitoring road traffic and various conceptual frameworks have been created for different countries on how these countries plan to implement UAVs in future. *Elloumi et al (2018)* have conducted a pilot study in which UAVs are used to monitor road traffic and adaptive UAV tracking is used over the standard fixed UAV trajectory method, to determine if this method is more efficient in terms of coverage of and detection rates of events (Elloumi, et al., 2018).

The assumptions for the road traffic monitoring (RTM) technique by *Elloumi et al* is as follows:

- Multiple UAVs are equipped with image processing capabilities and are all able to fly the desired period.
- Incidents can be observed and detected with perfect estimation, meaning accuracy in 100%.
- Detection of targets are always in the field of view (FoV) of the UAV, meaning no obstacles will obstruct vision.
- The UAVs can temporarily change their altitudes if needed, to avoid collisions.
- UAVs exchange information regarding the vehicles being tracked through the use of an identifier of the vehicle and its position.

Following this, the next issue that needed to be solved was to determine the number of UAVs needed to cover a city area. Target clusters were formed and each UAV would be assigned a set of targets. These target clusters were formed by using Vehicular Ad-Hoc Networks (VANETS) using distance between targets, target velocities and its direction of movement as parameters. To create these target clusters, an algorithm was created to perform this step, as described in Figure 2-11, with Table 2-5 providing the input variables. This step is an offline step allowing operators to estimate the number of UAVs needed. Assuming the total number of targets is known and identified with a label, position, speed and direction of movement, the algorithm can perform its desired job. *Elloumi et al* provides a deeper analysis of the algorithm that will not be assessed here.

```
j = 1 ; compt = 0
while compt < T_nb do
    while C_tag(j) == 1 do
        P_c(j) = Uniform (P_t)
    end
    C_tag(j) = 1 ; G(j, j) = C_id(j) ; compt = compt + 1
    for i = 1 to T_nb do
        if (T_tag(i) == 0) & (i ≠ j) &
         (M_t(i) == M_c(j)) & |V_t(i) − V_c(j)| < V &
         |P_t(i) − P_c(j)| < D then
            G(j, i) = T_id(i) ; compt = compt + 1
            T_tag(i) = 1
        end
    end
    j = j + 1
end
```

Figure 2-11: Algorithm for target clustering step (Elloumi, et al., 2018)

Table 2-5: Inputs for clustering Algorithm (Elloumi, et al., 2018)

T_{nb}	Targets numbers	D	Maximal distance value
V	Maximal velocities difference	P_t	Target position
V_t	Target velocity	M_t	Target direction of movement
P_c	Position of the central target	V_c	Velocity of the central target
$compt$	Number of covered targets	T_{tag}	Target tag
T_{id}	Target identifier	C_{tag}	Tag of the central target
C_{id}	Identifier of the central target	G	Groups members
M_c	Direction of the central target		

Once the number of UAVs is determined, the trajectory of these UAVs needed to be determined. *Elloumi et al* describes a detailed procedure considering three different approaches to cover a field of interest (for areas where vehicle counts are high such as at intersections and during congested flow). Figure 2-12 describes the three approaches. The first approach consists of communication between vehicles and ground sensors that UAVs use to determine its trajectory. The second approach uses static positioning that provides a FoV of a certain radius. The last approach considered is the proposition that *Elloumi et al* recommends, which consists of multiple UAVs that co-operate in real-time with image processing, that shares target information between each other.

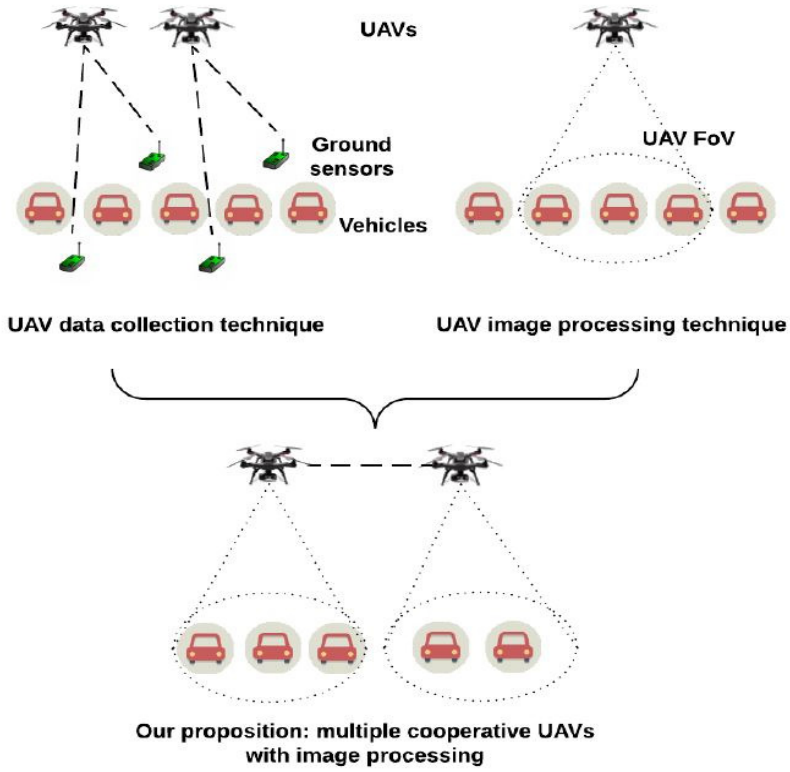

Figure 2-12: Three approaches to design UAV trajectories (Elloumi, et al., 2018)

Simulation results

Working on downtown Helsinki area (4.5 km X 3.4 km) with the three scenario containing 1000 targets spread out over the area, the following parameters were obtained from the drones:

Table 2-6: Simulation parameters (Elloumi, et al., 2018)

Parameters	Value
Simulation time	1000 s
Maximum car velocity	54 km/h
Minimum car velocity	36 km/h
Sampling interval	1 s
Number of cars	1000
UAV FoV radius	100 m

It is expected that about 250 UAVs would be needed to cover 1000 targets, with each UAV being capable of detecting speeding violations of speeds over 45 km/h (Elloumi, et al., 2018). In the point of interest (POI) approach, each UAV's trajectory is defined by the centre of gravity of its corresponding group of targets. Table 2-7 summarises the results of the study for each different approach, providing rates for different combinations of POIs and UAVs per 1000 targets.

Table 2-7: Results of tracking methods

(5 POI, 5 UAVs) / 1000 targets	Stationary Fixed POI method	Fixed POI method	Mobile POI method	Vehicular mobility based method
Coverage rate	3.01%	3.46%	4.32%	3.4%
Detection rate of speeding violations	2.88%	3.39%	3.98%	3.6%
Detection rate of speeding vehicles	30.31%	32%	45.11%	43.03%
Average duration of the detected speeding violations	17.18 sec	19.75 sec	18.14 sec	17.59 sec
Detection rate of congestion events	2.88%	3.11%	4.50%	3.39%
Average duration of the detected congestion events	118.62 sec	94.16 sec	88.62 sec	64.39 sec
(10 POI, 10 UAVs) / 1000 targets				
Coverage rate	5.66%	6.11%	7,42%	7.07%
Detection rate of speeding violations	6.13%	5.91%	6,54%	7.38%
Detection rate of speeding vehicles	44.95%	46.84%	63,40 %	66.73%
Average duration of the detected speeding violations	16.71 sec	18.65 sec	20,75 sec	23.34 sec
Detection rate of congestion events	5.42%	5.36%	8,61%	5.91%
Average duration of the detected congestion events	115.55 sec	86.14 sec	111,56 sec	66.13 sec
(20 POI, 20 UAVs) / 1000 targets				
Coverage rate	9.65%	10.63%	13.78%	12.45 %
Detection rate of speeding violations	8.99%	10.12%	12.95%	12.95%
Detection rate of speeding vehicles	58.83%	60.49%	82.12 %	82.53%
Average duration of the detected speeding violations	16.48 sec	17.43 sec	32.49 sec	33.51 sec
Detection rate of congestion events	9.52%	10.11%	14.83%	11.63%
Average duration of the detected congestion events	112.91 sec	79.27 sec	139.9 sec	100.54 sec
(25 POI, 25 UAVs) / 1000 targets				
Coverage rate	11.46%	12.82%	17.39%	17.15 %
Detection rate of speeding violations	10.41%	11.72%	16.44%	18.18%
Detection rate of speeding vehicles	60.29%	62.16%	90.02 %	89.39%
Average duration of the detected speeding violations	16.24 sec	17.1 sec	37.67 sec	41.36 sec
Detection rate of congestion events	11.8%	12.81%	18.62%	15.42%
Average duration of the detected congestion events	114.96 sec	82.04 sec	152.9 sec	125.18 sec
(30 POI, 30 UAVs) / 1000 targets				
Coverage rate	13.19%	15.34%	19.8%	19.36%
Detection rate of speeding violations	11.8%	13.97%	18.43%	20.75%
Detection rate of speeding vehicles	64.86%	69.02%	90.43%	90.02%
Average duration of the detected speeding violations	15.57 sec	16.59 sec	42.28 sec	47.42 sec
Detection rate of congestion events	13.83%	15.41%	20.17%	17.23%
Average duration of the detected congestion events	114.25 sec	80.99 sec	165.16 sec	138.20 sec
(40 POI, 40 UAVs) / 1000 targets				
Coverage rate	14.98%	17.66%	25.81%	25.88%
Detection rate of speeding violations	13.74%	16.5%	25.34%	26.06%
Detection rate of speeding vehicles	70.89%	76.29%	93.13%	93.13%
Average duration of the detected speeding violations	15.25 sec	16.25 sec	56.02 sec	57.13 sec
Detection rate of congestion events	15.8%	17.92%	24.67%	23.63%
Average duration of the detected congestion events	112.62 sec	78.46 sec	192.30 sec	181.45 sec
(50 POI, 50 UAVs) / 1000 targets				
Coverage rate	16.31%	19,27%	28.62%	28.28%
Detection rate of speeding violations	15.23%	18.27%	28.03%	30.09%
Detection rate of speeding vehicles	75.67%	80.87%	93.95%	93.76%
Average duration of the detected speeding violations	14.65 sec	15.95 sec	62.15 sec	63.72 sec
Detection rate of congestion events	17.24%	19.59%	27.48%	27.15%
Average duration of the detected congestion events	109.02 sec	74.29 sec	206.92 sec	191.54 sec

2.10.4.2 University of Florida – Airborne Traffic Surveillance Systems (ATSS)

Initiated by the University of Florida (UFL), the ATSS research team consists of UFL's research team, the FDOT, Tallahassee Commercial Airport and the University of North Florida Road Weather Information System (RWIS) Research Team (Srinivasan & Latchman, 2004). The research team nominated UFL's research team as the primary contractor for this project. The monitoring of remote and rural areas was the primary interest of this project to the FDOT. The ATSS proof-of-concept project aimed to evaluate the feasibility of wireless communication systems and serves as a case study for using UAVs in multimodal transportation and remote sensing. The SRA/Aerosonde was the chosen UAV vendor (Werner, 2003). This UAV can be seen in Figure 2-13 and the characteristics of it to this project are:

- Battery life ≈ 32 hours
- Altitude of flight = between 300 and 20000 feet above ground level
- Largely visible as can be seen in Figure 2-13
- The Aerosonde employs a Sony XC555 video camera which captures the video of the traffic on the highway
- A pair of Vaisala RSS901 weather detectors to gather freeway surveillance and RWIS data for transmission to FDOT microwave towers
- The data and video are transmitted using a 2.4 GHz wireless link

Figure 2-13: Aerosonde UAV (Werner, 2003)

The aim of this project was to show that the Aerosonde UAV can fly for a certain distance and successfully collect traffic information and transmit this to the base station. A Segment of highway between two FDOT microwave towers was chosen as the study area. The UAV is expected to capture and transmit the video in real-time while it flies along the highway aiming to investigate the integration of ATSS into the existing microwave network set up by FDOT, TMCs and State Emergency Operations Centre (SEOC). Figure 2-14 illustrates this process.

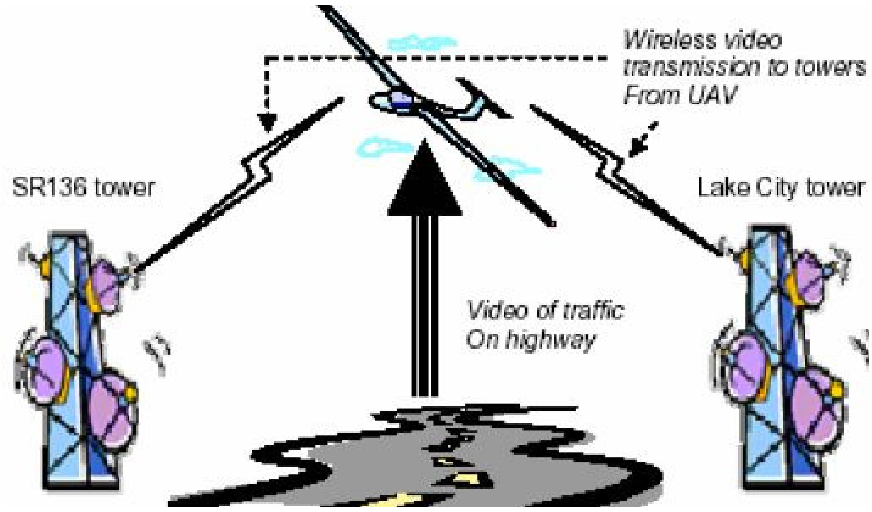

Figure 2-14: UAV video capturing on highway (Srinivasan & Latchman, 2004)

Videos from the UAV are sent to the base station, encodes it and transfers it to the FDOT network. Both towers would transmit different signals at different strengths and the SEOC would display the video of highway traffic received by the better signal. The handoff algorithm would also affect this video choice. This algorithm uses the constancy of the large scale signal variation relative to the base station to improve the receiving signal performance which is altered by changing the current signal due to movement of the mobile unit (the UAV) (Girma & Abebe, 2017). This part of the process is represented in Figure 2-15.

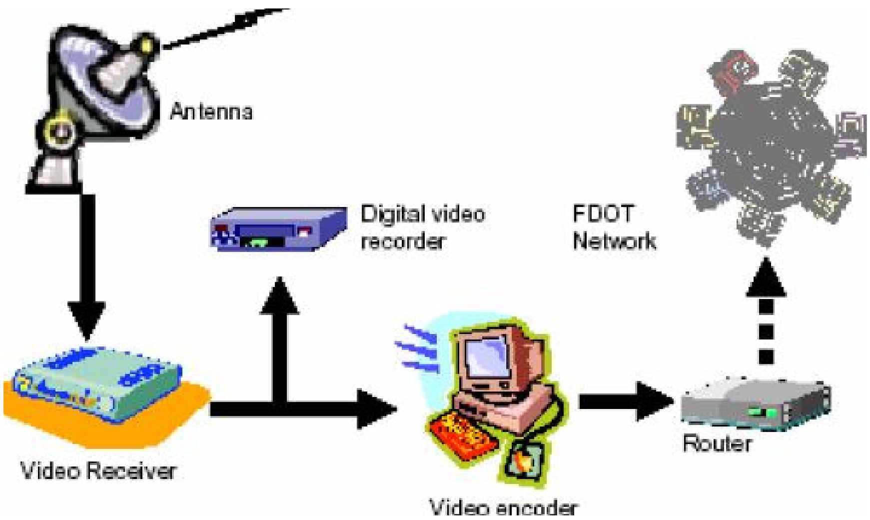

Figure 2-15: Video encoding and recording at microwave tower (Srinivasan & Latchman, 2004)

Two software programs, *SignalReader* and *VideoProcessor* have been developed by UFL for efficient communication and processing of received video signals (Srinivasan & Latchman, 2004). *SignalReader* uses an internal algorithm that parses (breaks into components) the read and received signal strengths into the correct format, decodes it and transmits the signal strength value of the microwave IP network. *VideoProcessor* receives the video signals from the two microwave towers and encodes them in Windows Media format allowing the video stream to be played using an embedded multimedia player. It also switches the video signals based on a handoff algorithm built into the program. This is indicated in Figure 2-16.

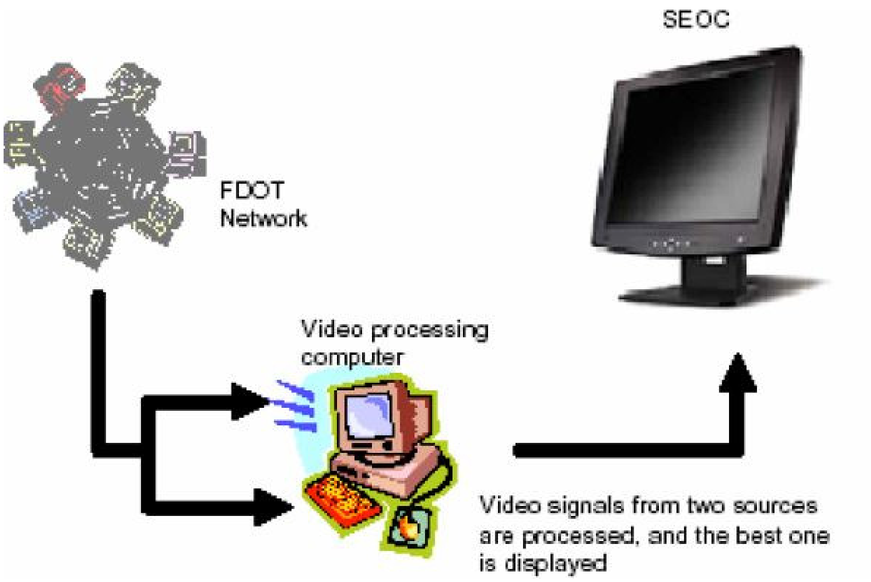

Figure 2-16: Video decoding and display (Srinivasan & Latchman, 2004)

Simulated tests that were carried out on three occasions; in December 2003, January 2004 and April 2004, using the described hardware and software to demonstrate the feasibility of the project. These tests demonstrated that the ATSS project is capable of supporting ground communications between the SEOC and the base towers.

2.10.4.3 Wallenberg Laboratory for Information Technology and Autonomous Systems (WITAS)

WITAS is conducting a long-term, multidisciplinary research project in cooperation with universities in USA, South America and Europe. The goal of this project is to develop functionalities and technologies necessary for the efficient and successful deployment of a fully autonomous UAV that operates over various different geographical terrain relating to road and traffic networks. The project involves integration of autonomy and active vision systems (digital video and infrared cameras) as well as a ground control dialogue system (Doherty, et al., 2000).

The intended actions of the UAV are to navigate different altitudes autonomously, plan for mission goals such as locating, identifying, tracking and monitoring different vehicle types and also to construct internal representations of its focus of attention for use in achieving the respective mission goals (Granlund, et al., 2000). The WITAS project also aims to identify complex behavioural patterns such as traversing of intersections, parking lot activities and vehicles overtaking. The goals of this ongoing research project are:

- Development of software and hardware systems with components for autonomous control of UAV platforms.
- Development of efficient algorithmic techniques which aids in assessing geographical, temporal and spatial information in the operational environment.
- Development of sensory platforms and interpretation techniques to deal with real-time constraints in processing sensory data.
- Development of a simulation, specification and verification techniques and modelling tools associated with the modelling tools of the project.

(Granlund, et al., 2000)

WITAS uses a conventional UAV setup consisting of the air vehicle with a video camera, a tactical ground station with operators (at a TMC) and a data-link between the air vehicle and station for transfer of images and data as well as for uploading of navigation and camera tool commands. The air vehicle WITAS uses is a Scandicraft Apid Mk III UAV which has a payload (weight it can carry) of 20 kg including fuel and a camera, indicated in Figure 2-17.

Figure 2-17: The Scandicraft Apid Mk III UAV (Doherty, et al., 2000)

The project is divided into four stages, namely:

- Stage 1 – data collection: Library and video sequences are collected from various vehicular traffic patterns.
- Stage 2 – development of controllers: The data collected is used as the basis for experimentation and development of sturdy controllers for the platform.

- Stage 3 – development of the on-board system: Initially, this was used from the ground to control the UAV and the ground system includes inputs of helicopter state and sensor information in addition to analogue video received via a radio-link.
- Stage 4 – this stage will integrate the system developed in Stage 3 and be placed on-board the platform where both semi and fully autonomous tests will occur.

The WITAS project uses a multi-layered reactive software architecture called Intelligent Vehicle Control Architecture (IVCA) containing two main information sources where data is stored, which are the Knowledge Structure Repository (KSR) and the Geographic Data Repository (GDR). The software architecture communicates directly with the core vision system. The vision system aims to determine the position, colour, type and velocity of the vehicles in the focus point of the camera. This involves accurately determining the position of the UAV and camera angles, mapping image coordinates to geographical coordinates and anchoring identified objects into qualitative descriptions of road segments, estimating relative motions of objects and indexing UAV camera views with the GDR to provide additional information relating to camera constraints.

At current, the project is at the end of stage 2 and a model-based simulation environment was developed to support the project goals. For the purpose of generating a realistic simulation environment, all the data collected was firstly collected using manned aerial helicopters and post-processed offline. Various scenarios were simulated in order to provide a broader understanding of the extent of the project goals and an example of such a simulation scenario can be found in Figure 2-18 which shows a tunnel in Stockholm.

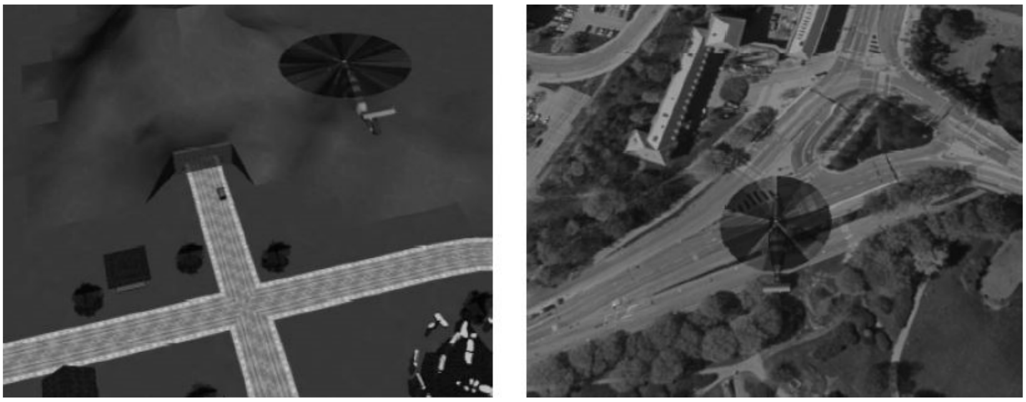

Figure 2-18: Virtual simulation of a traffic/tunnel scenario (Doherty, et al., 2000)

2.11 Conclusion of literature review

There is no doubt that effective traffic management is needed at all times to ensure that traffic flows smoothly and that traffic incidents are responded to and dealt with in a timeous manner. Large cities deal with traffic congestion caused by traffic events, fluctuations in normal traffic and, for some cities, lack of efficient transportation infrastructure. These large cities were found to manage traffic with TMSs which consist of various different phases, from gathering information to producing a management strategy. The roles of a TMS are carried out in a TMC, which acts as a base station for management of traffic throughout a city. In a TMC, various stakeholders representing different departments that run a city work together to achieve the TMC's desired goal.

In addition to normal TMC practices, which consists of CCTV cameras monitoring a road network and operators monitoring the feed from these cameras to respond to any incidents occurring, many countries were found to be moving towards using ITS in traffic management. The use of ITS provides better efficiency and it was found that ITS methods produce a wider variety of management methods which can aid in response to incidents and controlling traffic when incidents occur. With these ITS methods, the addition of UAVs has opened doors of possibilities providing a new angle to view traffic management at. These UAVs operate on a framework relevant to the TMC using them and these frameworks differ from country to country, although the main goal for using UAVs remain the same: to improve the efficiency of managing traffic.

Currently, the state of traffic management across the globe is at different stages for countries of different economic levels. Traffic management practices and the use of ITS and drones are increasing rapidly in first-world countries whereas third-world countries, although extensive research is being conducted to improve traffic management, are not developing as fast. There are many reasons for this, such as developing countries focusing more on providing primary services to its residents. This is evident in the research since most areas that are at the implementation stage for innovative traffic management are from first world countries. In terms of South Africa, innovation in traffic management has not been growing as rapidly as it would be expected to, although there is much room for growth.

In terms of future studies, scenario-based solutions to traffic management issues should be a possible aim for management centres, such as the research conducted by *Elloumi et al (2018).* This is because, at current, corporations are putting more attention in single-solution models instead of assessing the benefits and cons of different scenarios. Improved efficiency in traffic management can also be achieved by improving/altering existing infrastructure related to a TMC without introducing new hardware such as UAVs, and further studies should analyse this option before going directly to UAV-based Traffic Management Systems. More research should also be conducted in development of business and cost models for TMCs. This is where the goal of this thesis comes in: to develop two test models for providing traffic management for a small city and determine how to make one test model more economically feasible than the other while still providing enough functionality relating to traffic management processes.. The possible use of UAVs is also assessed in this thesis and how this will be incorporated with a TMC will be analysed as not much research has been conducted in this respect.

Chapter 3: Methodology

3.1 Introduction

This chapter provides the research strategy, an overview of the data analysis and research procedure, the selection of an appropriate study area and the limitations of this research.

3.2 Research strategy

A test model-based approach is followed to determine an appropriate traffic management model for a small city environment that would provide the necessary functionality while also being cost effective. A model-based approach allows for more than one model to be assessed, covering a greater range of traffic management possibilities.

Two different Test Models (TMs) will be investigated, testing two extremes: TM 1 considers the implementation of all Traffic Management Systems (TMSs) typically found in TMCs of large cities, and TM 2 considers the implementation of TMC systems and processes with limited infrastructure (the least amount of hardware, software and systems as possible). The setup of TM 2 is therefore based off how TM 1 is designed. The two extremes are tested to determine cost effective traffic management processes for a small city that still provides the necessary functionality. A cost breakdown of the components associated with TM 1 and TM 2 will be carried out and the level of functionality of TM 2 relative to TM 1 will also be determined. Finally, a discussion as to which TM would best suit a small city environment will be provided. The procedure of analysis is described in Figure 3-1.

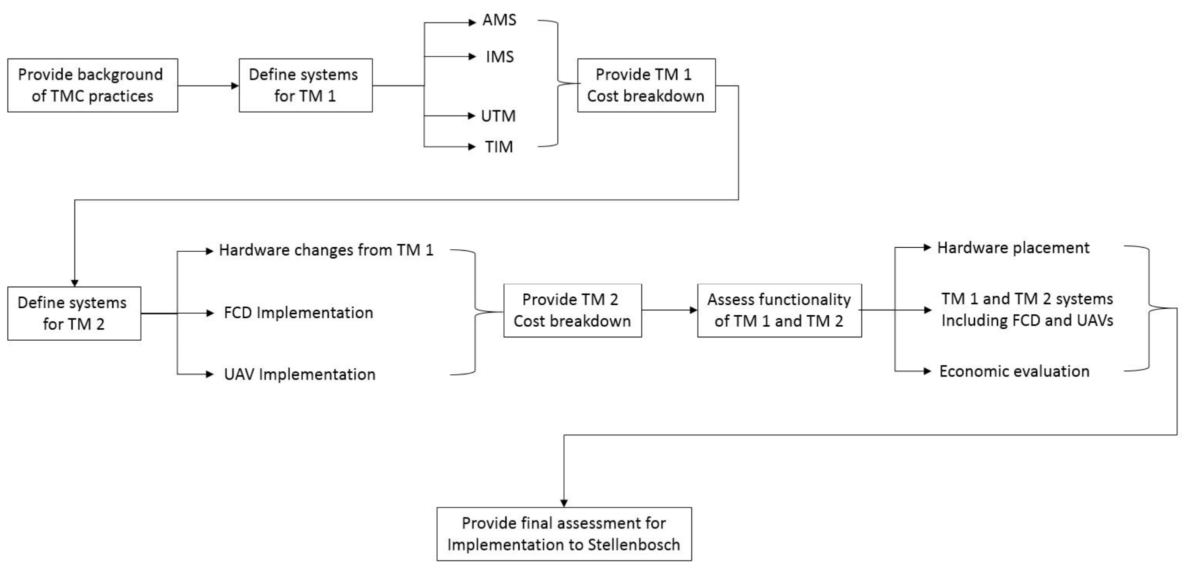

Figure 3-1: Analysis procedure followed

3.3 Description of Test Models

3.3.1 Test Model 1

TM 1 is based on the processes that occur in TMCs of large cities, such as in Cape Town. For the purpose of this research a TM 1 type TMC model developed for Stellenbosch will consist of the following TMSs:

1. Arterial Management System (AMS): An AMS manages traffic along arterial roadways by employing traffic detectors, traffic signals and different means of communicating information to travellers to smooth flow along routes travelled by road users.
2. Incident Management System (IMS): This is a combination of equipment, procedures communications use improve the reaction to emergencies. Conventionally, operators at a TMC deploy police services, Emergency Medical Services (EMS) or other IM services from the TMC in response to an emergency.
3. Urban Traffic Management (UTM): UTM refers to management and control of the road network and surrounding road features in urban areas.
4. Transport Information Management (TIM) with Pedestrian Management: Advanced Traveller Information Systems (ATIS) provide information to road users through various technologies, including Variable Message Signs (VMSs) and mobile applications. The management of collected data is also managed through a TIM.

The cost associated with implementing TM 1 in Stellenbosch will be determined.

3.3.2 Test Model 2

TM 2 will consist of the same four systems as TM 1, namely AMS, IMS, UTM and TIM. However, certain aspects of these systems will be altered or removed entirely to assess what functionality would be lost in the effort of making TM 2 more cost effective for a smaller city environment. Unmanned Aerial Vehicles (UAVs) and Floating Car Data (FCD) will be used in TM 2 to augment traffic management tools and the functionality that these facilities provide will be assessed.

3.4 Study area

The study area, Stellenbosch, is defined in terms of arterial management and urban management. This means that the portion of Stellenbosch used as the study area is made up of the arterials extending outward from Central Stellenbosch as well as the urban areas within the vicinity of Central Stellenbosch.

3.4.1 AMS coverage

In terms of the Western Cape Transport Infrastructure Act (Act 1 of 2013), arterial management plans are required for all municipal and provincial mobility routes, Class 1, 2 and 3 (Western Cape Government, 2016). The benefits of an effective arterial management plan are improved efficiency on the road network, shorter travel times due to relieved congestion and the provision of information to road users that allows them to make changes to their route in the event of traffic congestion.

Table 3-1 provides the arterials covered in this study (defined by intersection-to-intersection nomenclature) and the length associated with each road section. Roadway lengths were determined using Google Maps' Measurement Tool.

Table 3-1: AMS Coverage

Route	Road intersecting at route start	Road intersecting at route end	Map Identifier no.	Roadway length covered
R310	Annandale Road	M12	Roadway 1	5.16 km
R310	M12	R44 (Strand Road)	Roadway 2	4.25 km
R310	R44 (Strand Road)	R304 / Bird Street	Roadway 3	1.46 km
R310	R304	R310 (Helshoogte Road)	Roadway 4	349.8 m
Helshoogte Road	R44	R45	Roadway 5	15.74 km
R304	R310 / Bird Street	R101 (Old Paarl Road)	Roadway 6	11.67 km
R44	Helshoogte Road	R101 (Old Paarl Road)	Roadway 7	14.87 km
R44	Annandale Road	R310	Roadway 8	7.64 km
Total road length covered =				**61.14 km**

Based on the information provided in Table 3-1 as well as the TRH 26 Manual (2012), the arterials covered in this design were determined to be either class U2, U3, R2 or R3 (U – Urban, R – Rural), as indicated in Table 3-2. It should be noted that in accordance with a typical small city environment, there are no freeways in the Stellenbosch area, and the highest class of urban road is therefore U2.

Table 3-2: Roadway class and speed limit

Roadway	Road class
1	R2
2	U2
3	U3
4	U3
5	R2
6	R2
7	R2
8	U2

Figure 3-2 indicates the roadways described in Table 3-1 on a satellite view of Stellenbosch obtained using Google Earth. Circles of radii 5 km and 10 km from the centre of Stellenbosch are provided as a scale.

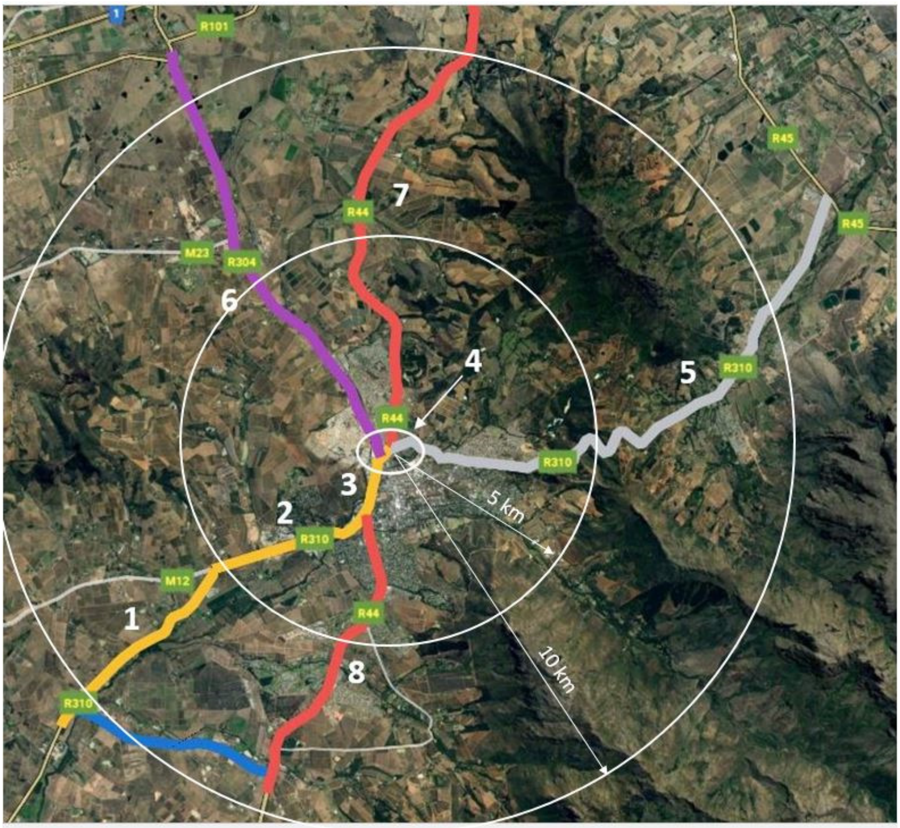

Figure 3-2: AMS coverage with defined roadways (↑N) (Google Earth, 2020)

3.4.2 Urban study area coverage

Figure 3-3 shows the urban areas covered in this study. The study area was chosen based on Google's traffic heat map where lower traffic speeds were observed on average throughout the day.

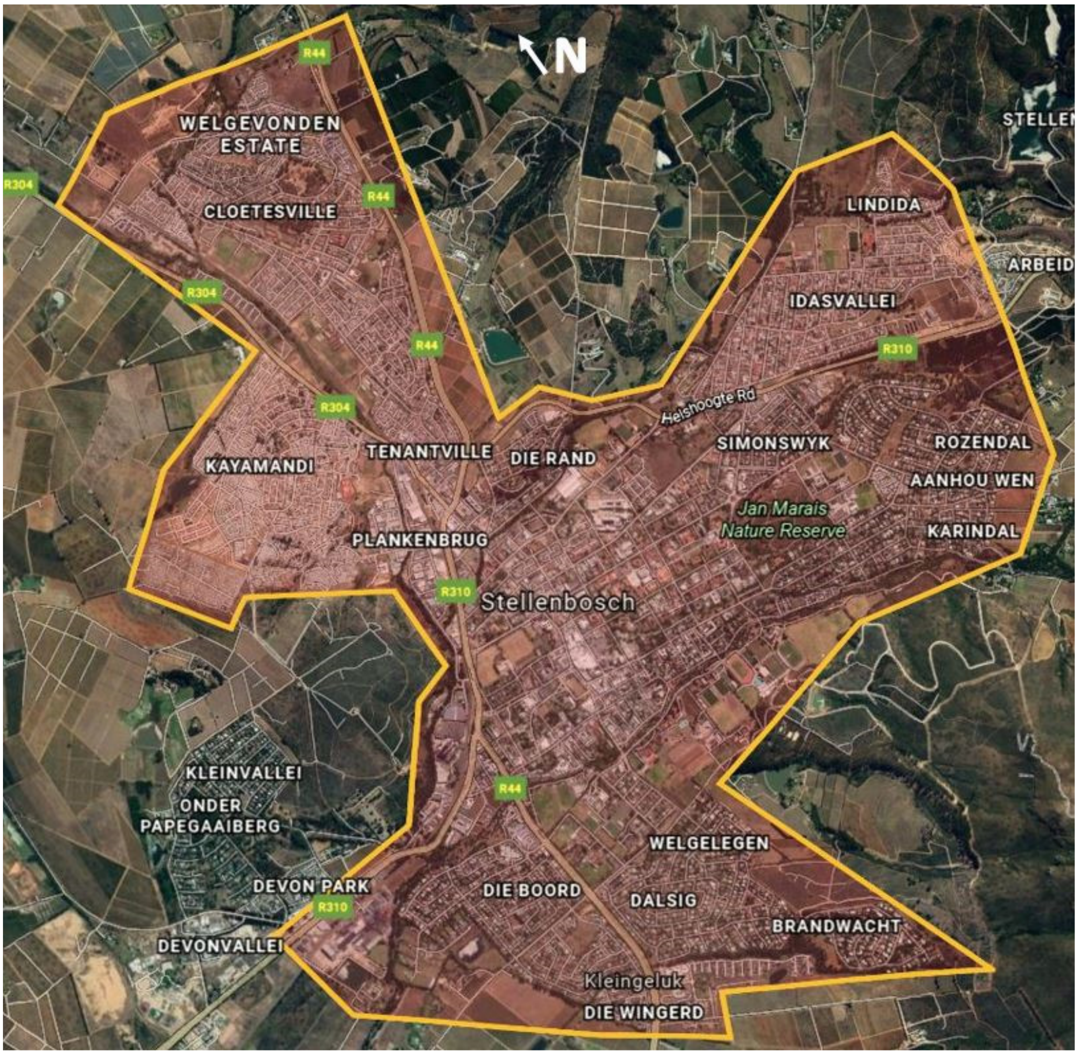

Figure 3-3: UTM Coverage

3.5 Data collection and analysis

Since this study will not consist of any on-site data collection or the extensive use of traffic management software to obtain data, the method of collecting data is mainly through research and observations of current traffic management processes. Furthermore, Google Maps and Google Earth are used for map images in this study, and Floating Car Data (FCD) used for speed and travel time analyses is obtained from TomTom®.

The data obtained in this study is used at a desktop level of analysis. No software, other than Microsoft Excel, was used to process data.

3.6 Limitations of study

The limitations related to this study are:

- This study was performed at a desktop level of analysis. No physical model of the study area was created.
- The data provided in this study is limited to the source of data. This means that certain datasets may not be for 2020 but rather for previous years due to the relevancy of data being determined by the institution or organisation who provides input data.
- No traffic management models, traffic management software packages or extensive data processing software were used in this study.
- The COVID-19 pandemic has resulted in meetings with people who would have provided data and information relating to traffic management being cancelled. This study was therefore limited by the pandemic to a certain extent.

Chapter 4: Test Model 1 (TM 1)

TM 1 aims to implement full traffic management processes used in TMCs in large cities, such as the TMC in Cape Town, to the study area. The four components of TM 1 identified for implementation in the Stellenbosch test area are: An Arterial Management System (AMS), Urban Traffic Management (UTM), an Incident Management System (IMS), and management of traffic information.

4.1 Arterial Management System (AMS)

The processes associated with the management of traffic incidents and the monitoring of traffic conditions on the arterial network within the study area are presented in this section.

4.1.2 AMS components

The AMS components required for TM 1 are:

4.1.2a) Field device: VMSs

VMS boards will be used throughout the study area to provide information to road users which aids them in decision making relating to traffic conditions, congestion or incidents ahead.

According to a presentation by Stuwig (2019), VMSs should be placed a minimum of approximately 800 m in advance of a point where a decision has to be made by a road user, 300 m (if possible) upstream or downstream of existing static sign gantries and on the road’s straight horizontal alignment so that it does not distract a user, causing them to lose control of their vehicle (Struwig, 2019). The VMS should also be adequately high so that road users can see the message it delivers from an acceptable distance. For arterials, the VMSs are placed prior to a decision point or at a location to provide information relating to traffic conditions at areas well after the VMS.

Detour routes could be indicated on the VMSs with travel times for these routes. Detour routes should be monitored to ensure that they themselves do not get congested. There will be a total of 9 VMSs. These will be placed to provide information to road users entering Stellenbosch.

VMSs will be placed as described in Table 4-1. Figure 4-1 shows an overarching view of where these VMSs will be placed.

Table 4-1: Placement of VMS boards

VMS Number	Location
1	Roadway 1 – On R310, ≈ 600 m from Annandale Rd + R310 intersection
2	Roadway 2 – On R310, ≈ 2 km from R310 + R44 intersection
3	Roadway 5 – On Helshoogte Rd (R310), ≈ 2.6 km from Helshoogte Rd + R44 intersection
4	Roadway 6 – On R304, ≈ 2 km from R304 + M23 intersection
5	Roadway 6 – On R304, ≈ 2.45 km from R304 + R310 intersection
6	Roadway 7 – On R44, ≈ 840 m before R44 + Muldersvlei Rd intersection
7	Roadway 7 – On R44, ≈ 300 m after Lang Road + R44 intersection
8	Roadway 8 – On R44, ≈ 650 m prior to Annandale Rd + R44 intersection
9	Roadway 8 – On R44, ≈ 145 m from Trumali Street + R44 intersection

Figure 4-1: VMS Locations

The VMSs locations were selected based on the following criteria to ensure adequate sight distance: straight roadway segments, minimal vertical change and no vegetation obstructing vision. The VMSs would also be 650 m before a decision point, such as an intersection or turn, to allow drivers enough time to make a route decision related to how traffic, accidents or road closures would affect their journey. Furthermore, detour routes with accompanying travel times will be provided if accidents, road closures or unexpected events causes congestion. The VMSs would provide information indicating these alternative routes. VMSs 1, 4, 6 and 8 are facing drivers entering Stellenbosch. VMSs 2, 3, 5, 7 and 9 are facing drivers exiting Stellenbosch. VMS 3 was chosen to face drivers exiting Stellenbosch and not drivers entering since at this location, drivers entering Stellenbosch would be close to Stellenbosch central and rerouting them through Stellenbosch will cause traffic congestion on other minor roads. Information related to weather conditions and traffic on Helshoogte Road would be beneficial to drivers exiting Stellenbosch.

4.1.2b) Field Device: CCTV cameras

CCTV cameras for monitoring roadways, detecting incidents and verifying accidents will be placed throughout the study area. For this AMP, CCTV cameras will be placed on all the arterials described in the study area.

CCTV cameras should be approximately 1 – 1.5 km apart although this is dependent on the geometry of the road and the direction the camera faces (cameras facing East-West will be affected by the glare of the sunrise/sunset). Cameras should also be placed on the outside of horizontal bends to ensure a larger field of view (FoV) (Struwig, 2019). CCTV cameras should also be placed in such a way as to not be obstructed by VMSs, vegetation or other tall structures.

The need for CCTV cameras can be motivated by the type of vehicle collisions that have occurred in and around Stellenbosch. Data describing the different types of accidents occurring in the period 2011 – 2016 for the R44 and R304 inbound was analysed to determine which accidents occur the most and was obtained from FCD provided by TomTom®. Of the 4504 accidents, 2189 of these were head/rear end collisions and 1039 of the 4504 accidents were vehicles that collided whilst approaching at an angle. The majority of these incidents occurred on Adam Tas Road and the R44, and cameras were placed accordingly to aid the incident detection procedure.

Figures 4-2 to 4-5 shows the placement of CCTV cameras for the eight roadways defined in this study. In total, there will be 25 CCTV cameras to provide a well-rounded area for coverage. Both intersections either side of Annandale Road experiences low traffic speeds during both peak AM and PM peak periods (based off Google Maps' colour-coded traffic speed map) and the two CCTVS on Annandale Road are to monitor vehicles that may detour through Annandale Road due to congestion. Cameras were labelled in an anti-clockwise direction and according to the Roadways defined in Figure 3-2 of Chapter 3. These are pan-tilt-zoom (PTZ) cameras which can be controlled by CCTV operators to inspect incident scenes. The cameras are positioned on mobility routes where low traffic speeds occur (based off Google's colour-coded heat map). The cameras are also positioned based off practical considerations. This means that cameras were placed to provide coverage of major intersections, on straight portions of road where vehicles might travel at higher speeds, and at intersections which provide entrance/exit to urban areas.

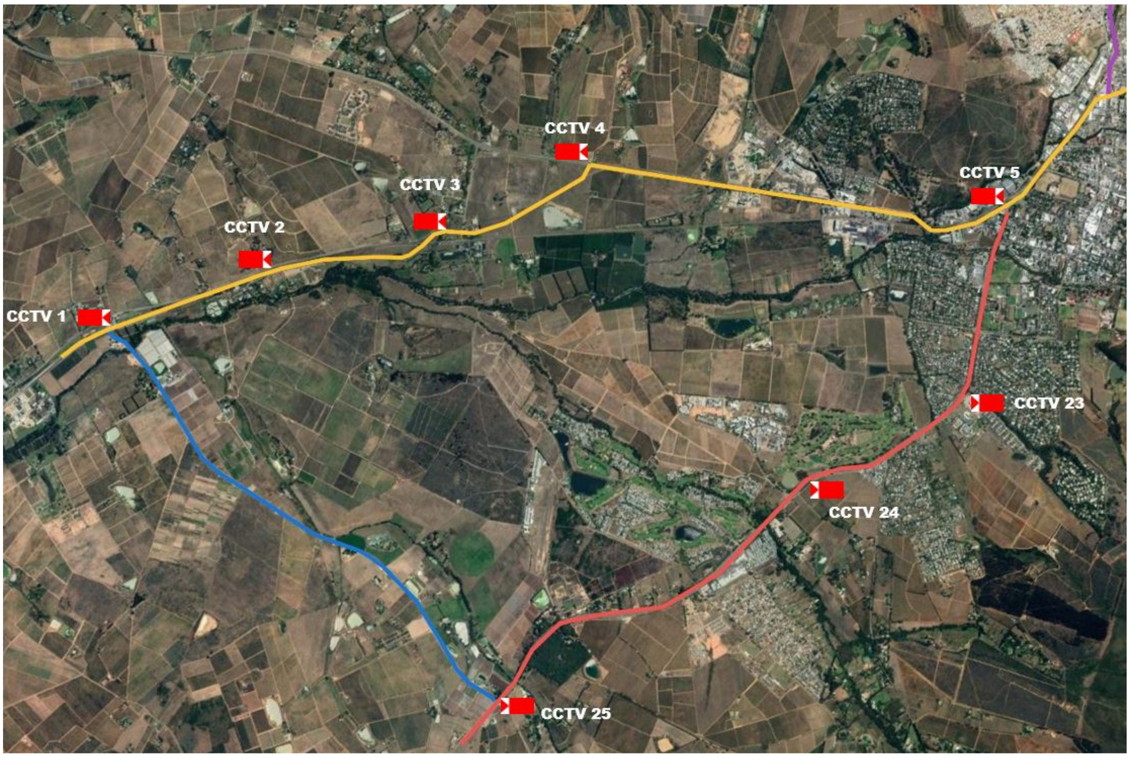

Figure 4-2: CCTV coverage for Roadways 1, 2, 3, 8

Figure 4-3: CCTV coverage for Roadway 4

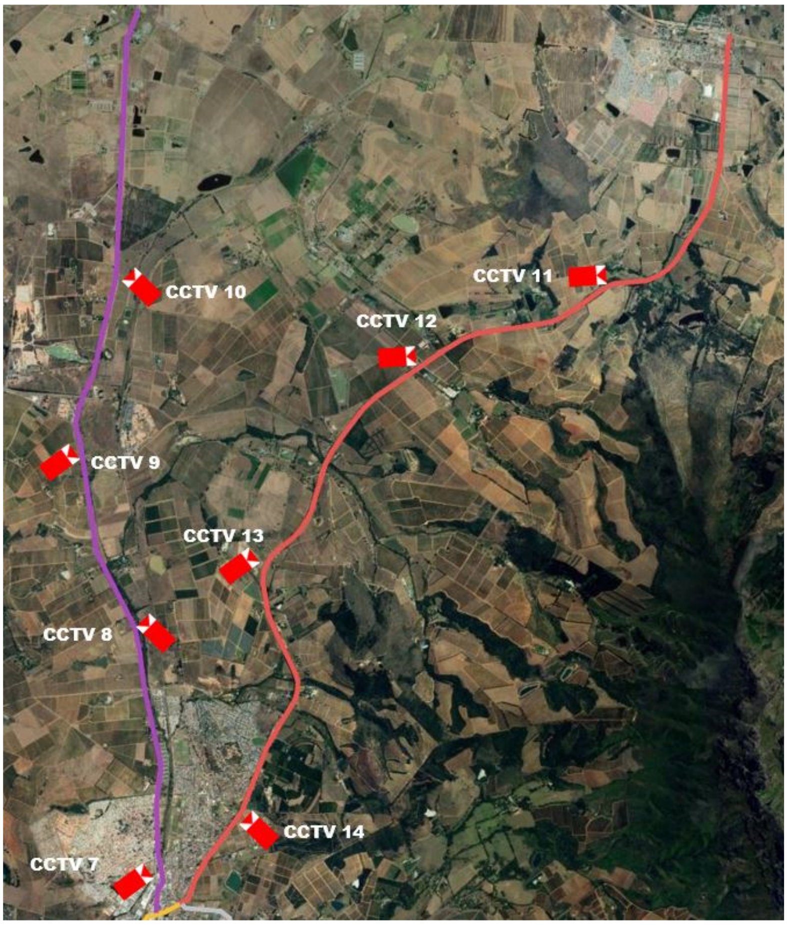

Figure 4-4: CCTV coverage for Roadways 6 and 7

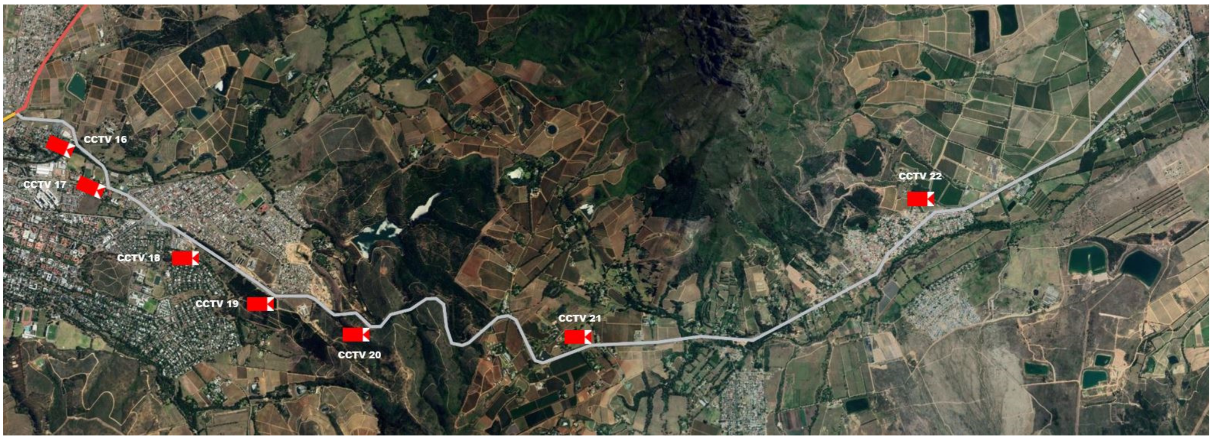

Figure 4-5: CCTV coverage for Roadway 5 (Helshoogte Road)

Table 4-2 shows a breakdown of the number of cameras and on which roadways these cameras are found.

Table 4-2: CCTV camera count and location

CCTV no.	Roadway
1 – 3	1
4	2
5	3
6, 15	4
7 – 10	6
11 – 14	7
16 – 22	5
23, 24, 25	8

Referring to Figures 4-2 through 4-5 and Table 4-2:

- Cameras were not strictly placed 1.5 km apart. Most camera placements did not adhere to this requirement since the road geometry and alignment were taken into account and the cameras were placed in such a way so that there would be a clear line of sight and minimal areas that were unobservable. Cameras can zoom just over 1 km, and can see clearly up to 800 m (as per correspondence with the Assistant TMC Manager at the Cape Town TMC, Deon Martin). Cameras have a field of view (FOV) of 53.8° (CCTV Direct, 2020)
- Cameras placements at certain sections, such as on portions of Helshoogte Road and the R44, were chosen based on the best position for a clear line of sight and the difficulty of installing cameras on these mountainous portions of road was not taken into account.

- No cameras were placed on the M23, Elsenburg Road or Annandale Road since these are out of the scope of this study.
- Cameras are to be positioned in the best manner to avoid facing east or west directly since sunrise/sunset will affect video quality.

4.1.2c) Field device: Vehicle Detection Sensors (VDSs)

VDSs are needed along the arterials in the study area to provide data such as average traffic speed, lane occupancy and vehicle classification and traffic volumes at different times of the day (Struwig, 2019). These datasets are used for various traffic management processes such as traffic signal control, traffic survey data or for detection of traffic violations. VDSs should be spaced at such intervals to provide sufficient density information and resolution for accurate data collection and travel time calculation, should share a location with CCTV cameras (if possible) and should not be obstructed by any structures.

VDSs are located at two places in the design for this study; sensors at intersections and sensors on roadways.

Intersection sensors

Intersection sensors will be placed at intersections where vehicle speeds are low (using Google Maps' colour-coded traffic map). Table 4-3 provides the locations for these sensors. These sensors are used to provide an understanding of the flow of traffic and be used to adjust signal phasing times if necessary. In total, there are 15 VDSs for intersections in the study area.

Table 4-3: Location of intersection sensors

Sensors for Roadways 1 – 4		
Intersection sensor no.	**Roadway**	**Location/at intersection of:**
1	1	R310 (Baden Powell) and Annandale Road
2	2	R310 (Baden Powell) and R310 (Polkadraai Road)
3	2	R310 (Adam Tas Road) and Dorp Street
4	3	R310 (Adam Tas Road) and R44 (Strand Road)
5	3	R310 (Adam Tas Road) and Merriman Avenue
6	4	R310 (Adam Tas Road) and Bird Street
7	4	R310 (Adam Tas Road) and R310 (Helshoogte Road)
Sensors for Roadway 5 (R310 – Helshoogte Road)		
8	5	Helshoogte Road and Hammanshand Road
9	5	Helshoogte Road and R45 (Franschoek Road)

Sensors for Roadway 6 (R304)		
10	6	R304 and entrance to Taxi Rank opposite Stellenbosch Motor Spares
11	6	R304 and M23
12	6	R304 and R101 (Old Paarl Road)
Sensors for Roadway 7 (R44)		
13	7	R44 and Kromme Rhee Road
14	7	R44 and R101 (Old Paarl Road)
Sensors for Roadway 8 (R44)		
15	8	R44 and Dorp Street

Roadway sensors

Due to sensors at intersections present, roadway sensors were spaced in such a way to cover the remaining road network not covered by these intersection sensors. Figures 4-6 to 4-8 shows these roadway sensors co-located with CCTV cameras on the different roadways. Roadway sensors were labelled in a counter-clockwise manner as for the CCTV cameras. In total, there will be 13 VDSs for the roadways of the arterials in the study area.

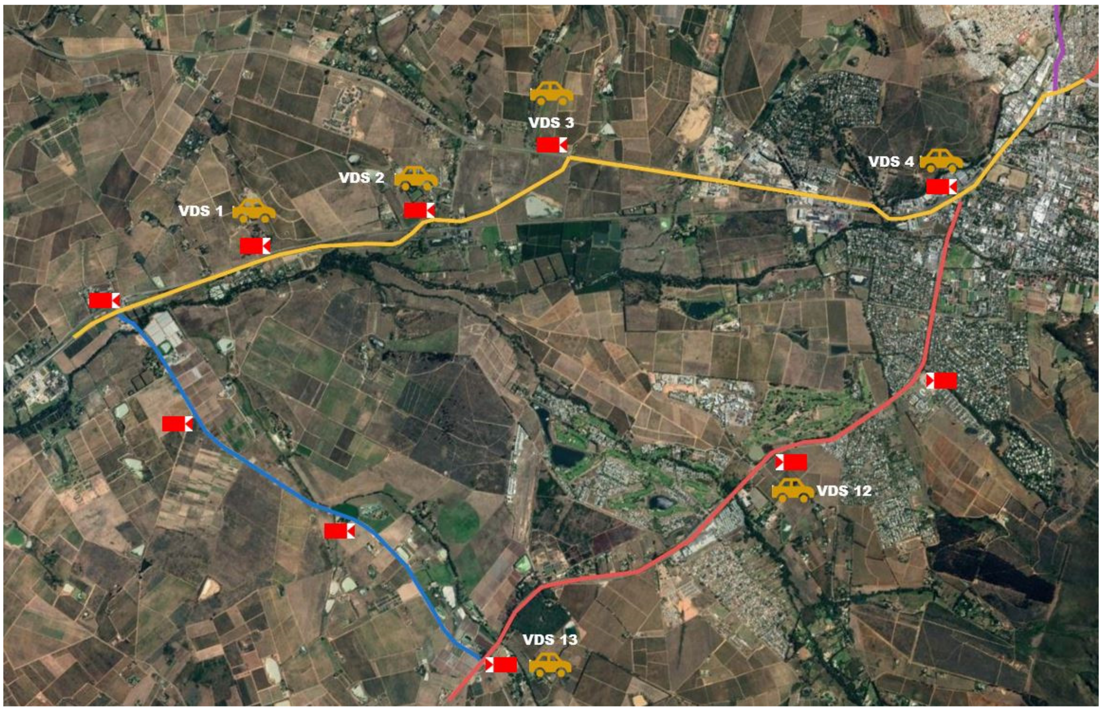

Figure 4-6: VDS coverage for Roadways 1, 2, 3, 4, 8 and Annandale Road

Figure 4-7: VDS coverage for Roadway 5 (Helshoogte Road)

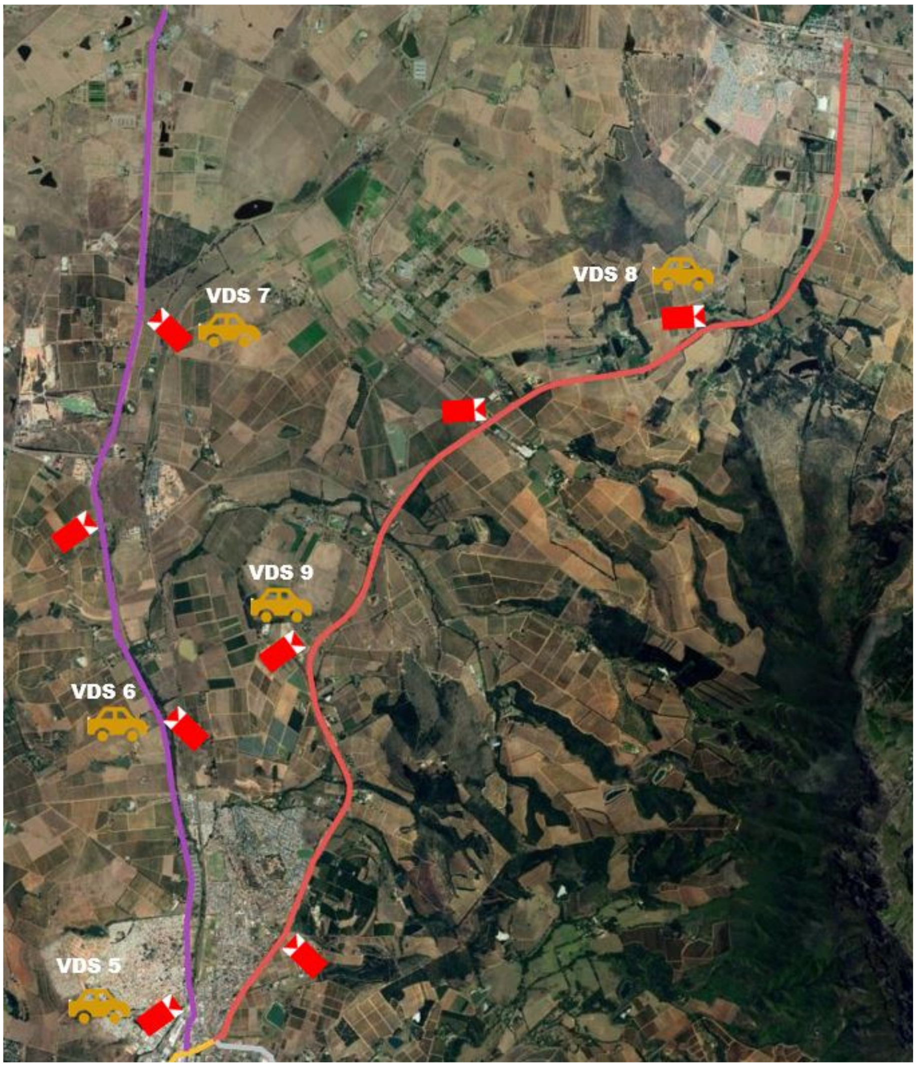

Figure 4-8: VDS coverage for Roadways 6 and 7

Table 4-4 shows a breakdown of the number of roadway sensors and on which roadways these VDSs are found.

Table 4-4: VDS count and location

VDS no.	Roadway
1 , 2	1
3	2
4	3
5, 6, 7	6
8, 9	7
10, 11	5
12, 13	8

From Figures 4-6 – 4-8:

- The position of VDS 1 was chosen based on the occurrence of events at Spier Wine Farm, where higher traffic may occur.
- No VDSs were placed on Annandale Road, the M23 or Elsenburg Road since traffic on these roadways are relatively low as compared to traffic on the arterials in the study area.

4.1.2d) Field device: Environmental Sensing Stations (ESSs)

ESSs provide information about how weather conditions affect the road network, including information relating to whether or not roads are slippery due to rain, visibility concerns in case of mist and presence extreme wind speeds, that are conveyed to road users via VMSs and also used in accident analyses. ESSs are placed in a 10 km radius adjacent to other stations (Struwig, 2019). Figure 4-9 shows the two ESSs for the study area.

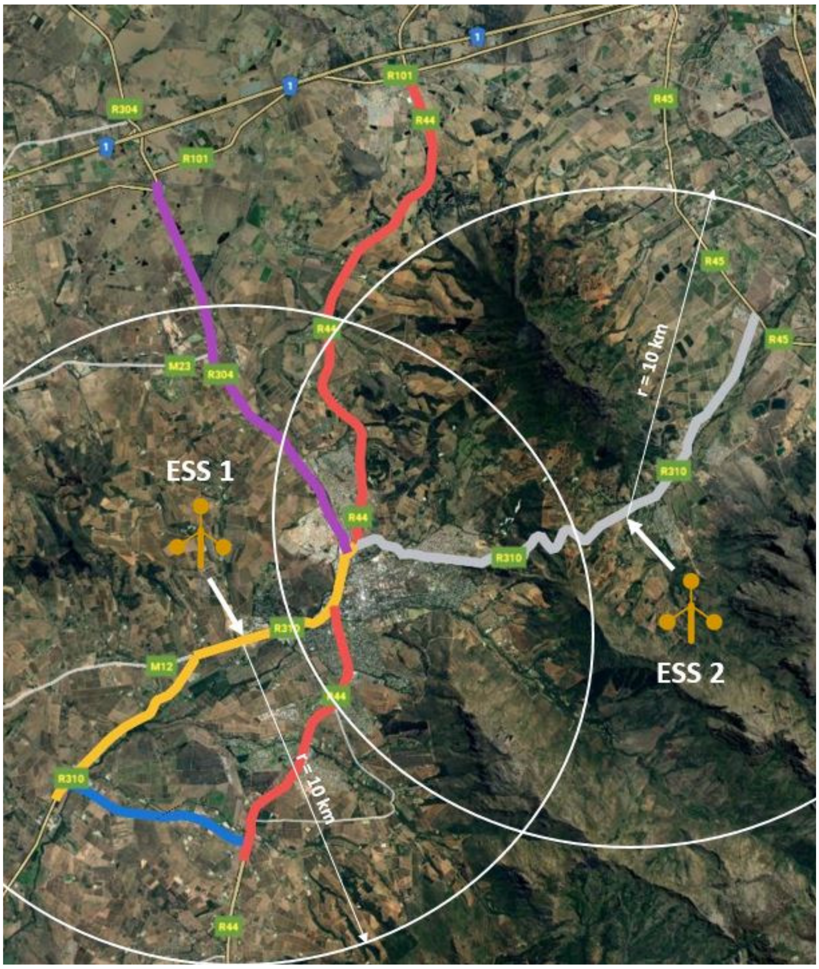

Figure 4-9: ESS coverage for arterial network

The ESSs were placed as indicated in Figure 4-9 for the following reasons:

- ESSs were placed so that overlapping radii are within a 10 km range as indicated in Figure 4-9. Each ESS would provide weather data for places up to 10 km away from the station. This ensures that the whole study area is covered.
- ESSs were placed spatially throughout the study area to provide weather data based off a more accurate average. For example, ESS 2 on Helshoogte Road would experience more extreme weather than the lower parts of Stellenbosch and weather data would be skewed if only the data from ESS 2 was used.
- Furthermore, the stations are co-located with CCTV cameras, away from any buildings or obstructions, with clear view of the sky and at least four times the height away from the building closest to it (Scientific, 1997).
- ESS 1 is located on the R310 adjacent to Devon Park and ESS 2 is on Helshoogte Road adjacent to Zorgvliet Wine Estate.

For the study area, there are three reasons, other than to provide general weather information, for the positions of the ESSs. These are:

1. To provide information when heavy rainfall occurs, which affects visibility of drivers and traffic on arterials.
2. To pick up high wind speeds so that drivers can be notified to be cautious (via VMSs) on sections of the road where horizontal alignment is steep.
3. To notify when dense fog occurs, which affects visibility of drivers.

4.2 Urban Traffic Management (UTM)

The management of traffic and traffic-related incidents in the urban areas of the study area are presented in this section. No traffic control measures such as roundabouts and adjustments to traffic signals will be provided. This study focuses on managing the current infrastructure of the study area. UTM consists of CCTV camera surveillance and the use of vehicle detection equipment.

4.2.1 CCTV cameras

A big aspect of the management of urban areas would be with the use of CCTV cameras. Similarly as for the AMS, CCTV cameras are placed in such a way to provide sufficient coverage of the urban road network, taking areas of high activity, intersection density and road priority into account. Urban CCTVs will not overlap with AMS CCTVs and will also provide coverage of pedestrian facilities. Figure 4-10 indicates how the study area was split up into areas of analysis.

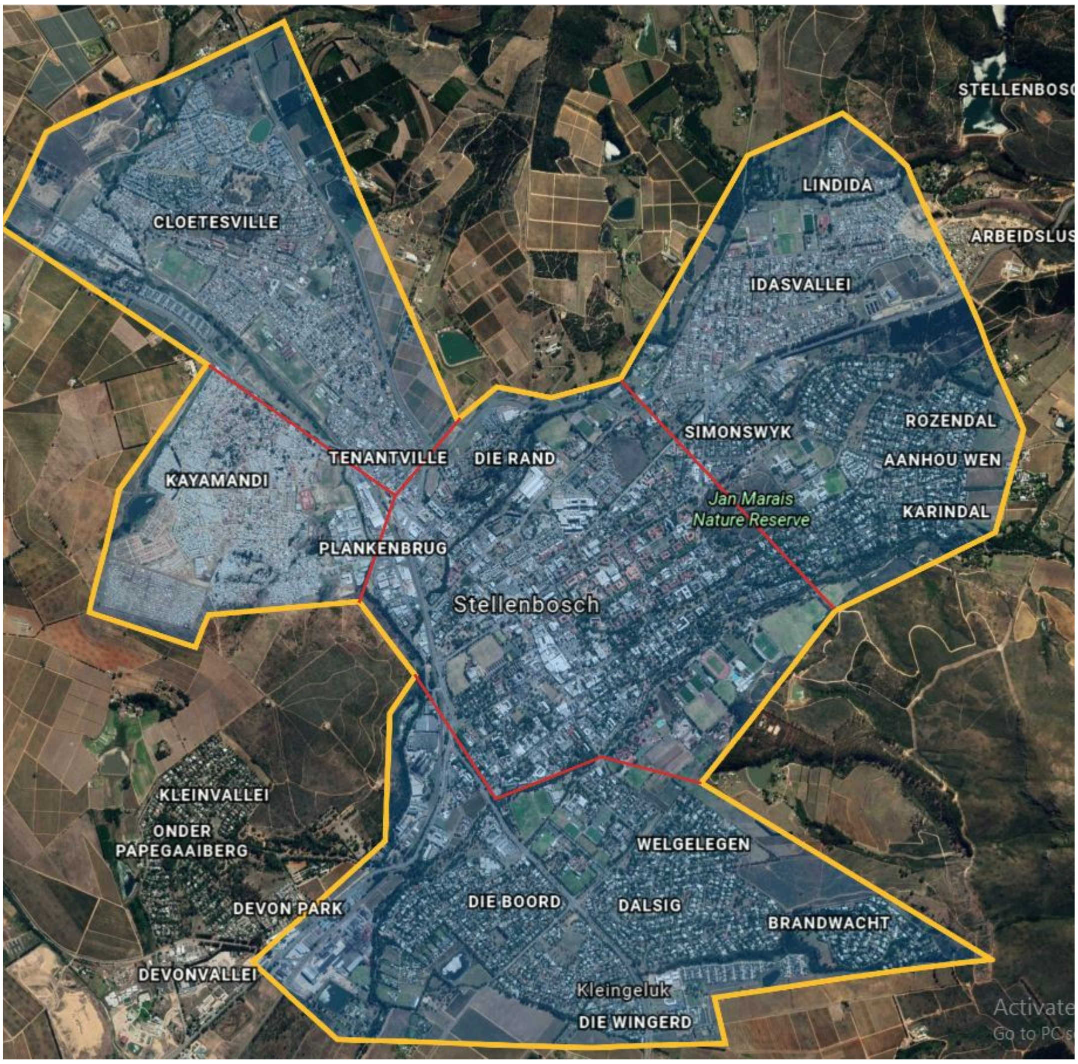

Figure 4-10: UTM area segmentation

The study area was split up into five segments as follows:

- Central: Stellenbosch central.
- Eastern: Idasvallei, Rozendal, Karindal, Simonswyk.
- Northern: Cloetesville, Tenantville.
- Western: Kayamandi, Plankenburg.
- Southern: Brandwacht, Die Boord, Dalsig, Welgelegen, Die Wingerd.

Figures 4-11 to 4-15 show the placement of CCTV cameras.

Figure 4-11: CCTV coverage for Central segment

Figure 4-12: CCTV coverage for Northern segment

Figure 4-13: CCTV coverage for Western segment

Figure 4-14: CCTV coverage for Southern segment

Figure 4-15: CCTV coverage for Eastern segment

Table 4-5 provides the intersections where these CCTV cameras are located.

Table 4-5: Location of CCTV cameras

CCTV no.	Location/At intersection of:
Segment: Central	
C1	Bird Street and Bell Road
C2	Bird Street and R310
C3	La Colline Road and Dan Pienaar Road
C4	Bird Street and Molteno Road
C5	Circle at intersection of Hammanshand Road and entrance to Stellenbosch University's Engineering Parking Lot
C6	Banghoek Road and Bosman Street
C7	Circle at intersection of Merriman Avenue, Soeteweide Road, Cluver Road and Marais Road
C8	Merriman Avenue and Bosman Street
C9	Merriman Avenue and Bird Street
C10	On Bird Street between Bird Street, Plein Street circle and Bird Street, Alexander Street circle
C11	Victoria Street and Neethling Street
C12	Dorp Street and Mill Street
C13	Van Riebeeck Street and Coetzenburg Street
Segment: Northern	
N1	R44 and Hendrikse Road
N2	Gabriels Road and Lang Road
N3	Chippendale Road and Lang Road
N4	Last Road and Lang Road
N5	Last Road and Curry Road
N6	Noble Road and Curry Road
Segment: Western	
W1	R304 and Mount Simon Drive
W2	Sokuqala Street and Makupula Road
W3	Manyano Road and Makupula Road
W4	Circle at intersection of George Blake Street and Masitandane Road

W5	Bassi Road and Vineyard Street
W6	School Crescent and 13th Street
W7	Tata Mandela Drive and Winnie Mandela Drive
Segment: Southern	
S1	R44 (Strand Road) and Saffraan Street
S2	Saffraan Avenue and Lovell Road
S3	R44 (Strand Road) and Van Reede Road
S4	R310 (Adam Tas Road) and Oude Libertas Road
S5	Brandwacht Road and Le Seuer Road
Segment: Eastern	
E1	Davy Street and Hector Street
E2	Old Helshoogte Road and Protea Street
E3	Cluver Road and Banghoek Road
E4	Jonkershoek Road and Omega Road
E5	Martinson Road and Morkel Road

It total, there are 36 CCTV cameras for urban area coverage and these cameras were placed according to the main routes followed to get into or out of an urban area as well as to provide extra surveillance for safety.

4.2.2 Video detection sensors and induction loops

In addition to the surveillance provided by CCTV cameras, video detection software will be used at relatively dense intersections as compared to other intersections in the study area to collect vehicle data such as number of vehicles and headways and to provide better management of the road network. The information obtained from the video feed will be processes and analysed in the TMC and can be used to relieve congestion by optimising cycle lengths or changing green times. Induction loops will be installed at selected roadways that do not have high traffic volumes but where traffic data is needed.

Table 4-6 provides the locations of the video detection sensors and induction loops. These are co-located with the urban CCTV cameras.

Table 4-6: Location of video detection sensors and induction loops

Traffic data collection method	Location/At CCTV no.:	Total
Video detection sensors	C2, C4, C6, C12, N1, W1, S1, S3, E5	9
Induction loops	C10, N8	2

Since loops are not spaced at equivalent intervals, the delay at which data is received cannot be determined. The delay with data transmission per individual loop is estimated as 30 seconds – it takes 30 seconds for data to travel from the loop to the system it is being used in (Kessler, et al., 2018). This is due to detector data taking approximately one minute to aggregate.

4.3 Incident Management System (IMS)

The procedures, personnel, equipment and communications and combinations of these components to provide efficient incident management are presented in this section.

4.3.1 IMS coverage

The IMS coverage consists of the same eight arterial roadways as defined for the AMS as well as the urban road network as defined for the UTM. A total of 61.14 km of arterial roads are therefore covered by the IMS. The IMS also responds to incidents in the urban area network.

4.3.2 Location of base stations and response units

Figure 4-16 indicates the locations singular Unit Station where emergency response units will be housed for deployment. Deployment, management and traffic control decisions are made in the TMC itself.

Figure 4-16: Location of base stations

The position of the Unit Station was chosen based on the current location of Stellenbosch's Fire and Rescue Unit. The functionality of this location is tested in Chapter 6. The goal of this Unit Station is to respond in less than 15 minutes, the world average, to any incident scene within the study area (Seaman, 2017). Units can also be stored at and deployed from the garage space at the intersection of Molteno Road and the R310 (Adam Tas Road) (immediately west of the Unit Station on the R310, as indicated in Figure 4-16).

Table 4-7 indicates the type and number of response units dispatched, the crew associated with these units and a short description of the unit's duty.

Table 4-7: Description of response units stationed at Unit Station

Type of response unit	**Quantity**	**Crew associated per response unit**	**Duty**
Incident Response Unit (IRU)	3	• 1 Traffic safety officer • 1 basic life support paramedics • 2 Flagmen	• Secure incident scene • Deploy signage for same resumption of traffic operations • Offer basic life support to injured persons
Medical Response Unit (MRU)	2	• 1 Intermediate life support paramedics	• Provide rapid medical response • Stabilise critical patients until ambulance arrives on scene
Light Towing Unit (LTU)	2	• 1 Driver	• Move broken down passenger vehicles or motorcycles off roadway so that traffic is not obstructed
Heavy Towing Unit (HTU)	1	• 1 Driver	• Move broken down trucks or buses off roadway
Number of personnel employed			**17**
Traffic safety officers			**3**
Basic life support paramedics			**3**
Flagmen			**6**
Intermediate life support paramedic			**2**
LTU and HTU Drivers			**3**

From Table 4-7:

- Three IRU units are chosen for the study area to ensure that the response to any incident scene is swift and efficient, in the case of more than one incident within the same time period.
- IRUs, MRUs, LTUs and HTUs are stationed central to be deployed to any incident in the study area if need be.

The personnel of the IMS will work alongside private medical response, towing and fire and rescue services. Furthermore, a representative from neighbourhood watch from each five sections of the UTM will be present in the TMC providing updates obtained from social media (It should be noted that these response units are based on a theoretical analysis of the study area, meaning that towing services that are already in place have not been taken into account. The LTUs and HTUs in the IMS of this study are provided to ensure a holistic coverage for all incident types that may occur. The same reasoning applies for the MRU since medical response services such as Netcare and ER24 may possibly operate in Stellenbosch).

4.3.3 IMS software

The software used in the TMC to provide efficient incident management is used for different tasks and for different components of the incident management process. Table 4-8 shows these tasks for this study.

Table 4-8: IMS software

IMS process category	IMS software task
Detection and verification	• Incidents will be detected via social media updates, queue monitoring and video detection software.
Traveller information	• Real-time incident information will be provided to media and displayed on VMSs
Responses	• Automated Vehicle Location (AVL) computer aided dispatch will be used to track and navigate response units • Pre-emption of traffic signals for emergency vehicles to reduce the possibility of an accident while travelling to the incident scene as well as improving response time
Scene management and traffic control	• Real-time traffic diversion with aiding map software • Pre-planned diversion routes will be ready in case of incidents at hot spots • Deployment of response units and VMS updates.
Incident clearance and recovery	• Updating VMS to notify road users of resumption of normal traffic operations

4.3.4 IMS process

The overall process followed to ensure that an incident is managed effectively in the study area is provided in Figure 4-17. The duration of the incident is from when the incident occurs to the time at which normal traffic flow resumes. Within this period, incident verification and response as well as a site investigation and clearance occurs, and the appropriate incident management team is deployed to carry out these steps.

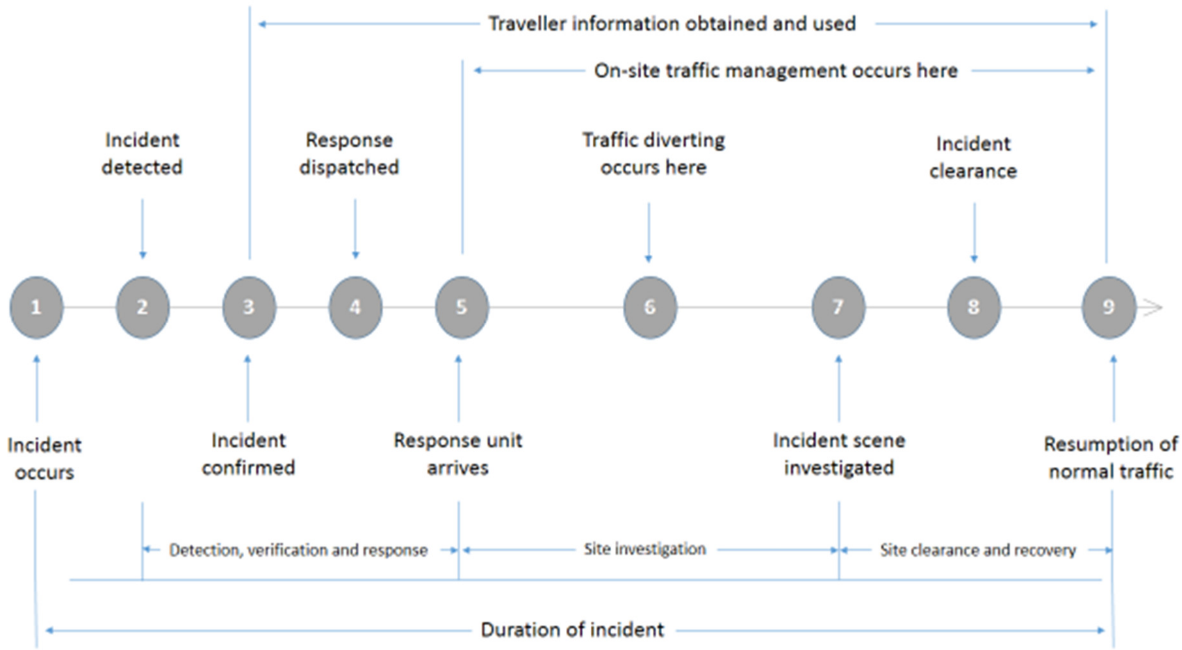

Figure 4-17: IMS process

4.4 Traffic Information Management (TIM)

In order for the efficient operation and management of traffic processes, information required for traffic analyses is required. More importantly, the management of this information so that it can be accessed and used easily is crucial to controlling traffic and traffic incidents. Table 4-9 provides the type of information obtained, how it is stored and how it is accessed for the three key sectors of traffic management for Stellenbosch; namely the AMS, UTM and IMS.

Table 4-9: TIM

Information obtained	**Sector where information is used**	**Information management**
CCTV footage	AMS, UTM, IMS	CCTV footage is stored in a database on the hard drives at the TMC where it is used.
Induction loop input	UTM	Induction loop data is stored in a database and used with the RITIS database in traffic analyses.
VDS data	AMS	Stored in the RITIS database and used for traffic analyses.
Environment information	AMS	Stored in the RITIS database and used for traffic analyses.
Road user input via telephone line	AMS, UTM, IMS	Road user input is used to provide aid at the reported incident/accident and calls are logged.
Video detection sensors	UTM	Stored in the RITIS database and used for traffic analyses.
Social media input	AMS, UTM, IMS	Social media personnel collects and assesses input from social media and provides updates via different social media platforms.
Work zone data	Construction/ maintenance	Work zone data is logged to ensure that proper road work maintenance is in place and that construction is tracked.
Incident data	IMS	Incident data obtained from video footage or user inputs (social media and telephonically) is used to dispatch the appropriate incident response team.

4.5 Cost breakdown for TM 1

The costs associated with the implementation of TM 1 are presented in this section. A detailed cost breakdown for each sector of traffic management is provided; namely the AMS, UTM, IMS and TIM. Costs provided are based on 2020 costs obtained from SANRAL and from resources online.

4.5.1 Costs associated with the AMS

The costs associated with hardware and equipment for the AMS are described below. 2020 Cost estimates were established with the assistance of SANRAL. The costs supplied are based on these devices being installed as a complete operational system. The prices provided are for the installations that SANRAL were responsible for in the Western Cape and the rates have been escalated from 2011 Tender rates.

4.5.1a) CCTV coverage

- **Camera specifications**: Internet Protocol (IP) cameras are used, since the footage obtained from these cameras can be accessed directly without the need of a decoder. 2 Megapixel Pan-tilt-zoom (PTZ) cameras with 1920 x 1080 high definition recording quality are used. The cameras are also equipped with license plate recognition. The infrastructure for the CCTV cameras to be put up include the mass concrete base, 13 metre galvanised steel pole, electronic and electrical components, fibre splicing components and the mounting bracket for which the camera is mounted with. The unit cost for one CCTV camera and associated infrastructure is R200,371.28.
- **CCTV operators**: Since 25 CCTV cameras need to be monitored, each CCTV operator can monitor 15 CCTVs on one screen. Working 8 hour shifts, 6 CCTV operators are required (2 operators per 8 hour shift). CCTV footage of areas with high incident rates can be viewed by both operators on the extra screen space (since on operator would view 13 screens and the other 12 if the 25 cameras were split down the middle). With an average hourly pay rate of approximately R42.00 in South Africa, each operator's monthly salary is R10,000.00. Other tasks such as displaying VMS messages and analysing VDS and ESS data are also dealt with by these staff members. Furthermore, a TMC Manager is in place who earns R45,000.00 per month, as well as an assistant TMC Manager who earns R30,000.00 per month and a TMC Supervisor who earns R18,500.00 per month.
- **CCTV operator workstation**: Each operator station is equipped with an Intel® i7 PC with Windows 7 operating system and 2 x 20 inch LCD monitor (one screen would be for viewing CCTV footage and the other for managing traffic software). The unit cost for the PC and monitor package (with associated hardware) is R42,894.11.

FMS CCTV operators at Cape Town's TMC monitor roughly 50 CCTV cameras on two screens, 25 CCTVs on each screen (Martin, 2020). For this study the number of cameras each operator monitors were less to reduce the time delay in perceiving and reacting to an incident as found by Birungi (2019) (Birungi, 2019).

4.5.1b) VMS, VDS and ESS coverage

- The **VMSs** used are overhead signs that display linear sentences over the full width of the sign. The infrastructure associated with the VMS includes the concrete base mass, mounting gantry, electrical and electronic components, fibre splicing components and 16 batteries per VMS unit. The unit cost of the VMS and associated infrastructure is R581,620.00.
- **VDS**: Infrared video sensing equipment is used for obtaining vehicle detection data. The infrastructure associated with the VDS is an 8 metre galvanised pole, VDS mounting bracket, electronic cabling, communications equipment and fibre splicing components. The unit cost of a sensor and associated infrastructure is R105,010.00. This cost is for both roadway and intersection sensors since the same type of sensor is used.
- **ESS**: A Wireless (with GPRS capabilities) HP2000 weather station is used in this study. The ESS consists of an 8 metre galvanised pole, measurement and control data logger, rain gauge, temperature, visibility and wind sensors, electronic cabling, communications equipment and fibre splicing components. The unit cost associated with the ESS is R163,985.00.

4.5.1c) Server room and maintenance

- **Server room**: For the server room which receives data, the minimum requirement is an Intel Xeon 5130 2.0GHz/4MB processor with a standard 500GB SATA hard drive (HDD). Since one hard drive can serve 8 cameras on a yearly basis, 4 hard drives are required. The cost of the Xeon processor is R74585 and the unit cost of the hard drive is R906 (ComX Computers, 2020), (PriceCheck, 2020). The server room collects and stores data for the other components of TM 1 as well; namely the UTM, IMS and TIM components.
- **Maintenance**: Maintenance on all hardware associated with the AMS will be conducted every 2 years. Maintenance will be done by an external consulting engineering company with a projected cost of 15% of the initial cost of hardware associated with the AMS.
- **Outstation**: An outstation is also present for data collection and integration with local traffic management equipment. For Stellenbosch, only one would be necessary. The unit cost of this outstation is R155,296.25.

4.5.2 Costs associated with UTM

- The same PTZ **CCTV cameras** used for the AMS are used to manage urban traffic. The same VDSs are used as well to ensure consistency when maintenance needs to be done.
- **Urban CCTV operators**: Since 36 cameras need to be monitored, 6 urban CCTV operators are employed (8 hour shifts with each operator monitoring 19 cameras). These operators also earn R10,000.00 each. These operators do not require PCs as advanced as the ones AMS CCTV camera operators use since urban CCTV cameras are more for surveillance. These operators will assist in other areas such as correspondence with neighbourhood watch and managing social media platforms in addition to monitoring urban CCTV cameras.
- **Induction loops**: There are three intersection induction loops and one roadway loop present in the UTM plan. The intersection loop consists of four legs, spanning over all the lanes approaching the intersections. These are wired to the control box at the respective intersection. The roadway sensor consists of a double set (four) loops with controller and power box. The unit cost of an intersection sensor with power supply is R10,456.32 and the cost of the magnetic stop bar detectors is R44,521.60 (Sobie, 2016). The cost of a roadway sensor is R20,934.48 (US Department of Transport, 2020).

4.5.3 Costs associated with the IMS

- **Incident Response Units (IRUs):** To transport the crew members of the IRU, a 2018 Toyota Hilux Double Cab was chosen as the IRU unit vehicle. This vehicle is big enough to accommodate all crew members as well as the relevant equipment needed. The unit cost of this vehicle brand new is R326000 (Imperial Toyota, 2020). Note that the salaries of traffic safety officers are not provided as these people already patrol in Stellenbosch.
- **Medical Response Units (MRUs):** To transport the MRU crew members, a 2018 Toyota Corolla is used with a unit cost of R318,500.00 (Imperial Toyota, 2020).
- **IRU and MRU equipment:** Traffic signage, traffic accommodating equipment and a basic life support jump bag are required in the IRUs and MRUs. The unit cost of a jump bag with relevant medical supplies is R4,429.95 (The Paramedic Shop, 2020). Traffic accommodating equipment vary per situation and R8,000.00 will be allocated per IRU (Roadquip, 2020).
- **Light and Heavy Towing Units (LTUs and HTUs):** LTUs capable of hauling light passenger vehicles and mini vans are required and Tata's LTUs with a unit cost of R300,000.00 were chosen for this project. Isuzu's HTU for larger vehicles are used, with a unit cost of R375,000.00. (OLX, 2020).

4.5.4 Costs associated with TIM

- To manage the collection, processing, analysing and use of data, the TRAFMAN software from Magna is used. This is a licensed product since a cloud database is not used and the cost per year is estimated at R25,000.00.
- Two traffic management software specialists are employed who earns a monthly salary of R19,750.00 (Payscale, 2020).

4.5.5 Summary of costs associated with TM 1

Table 4-10 provides a summary of the costs associated with setting up TM 1 and its associated hardware, vehicles and equipment.

Table 4-10: Summary of cost of hardware, vehicles and equipment for TM 1

COST BREAKDOWN FOR COMPONENTS OF TM1				
Arterial Management System (AMS)				
Component	Description	Quantity	Unit Cost (Rand)	Cost (Rand)
CCTV cameras	PTZ 2MP high def cameras	25	200371.3	5009282
CCTV workstations	PC and accessories	2	42894.11	85788.22
VMSs	Overhead message sign	9	581620	5234580
Intersection VDSs	Infrared video sensing equipment	15	105010	1575150
Roadway VDSs	Infrared video sensing equipment	13	105010	1365130
ESS	Wireless weather station with data logger	2	163985	327970
Server processor	Intel Xeon 5130 2.0GHz/4MB processor	1	74585	74585
Server room HDDs	500GB standard SATA hard drive	4	906	3624
Outstation	Station for data collection and TM assessment	1	155296.3	155296.25
		AMS Total cost =		R 13,831,405.47
Urban Traffic Management (UTM)				
CCTV cameras	PTZ 2MP high def cameras	36	200371.3	7213366.08
VDSs	Infrared video sensing equipment	9	105010	945090
Induction loop: Intersection	Intersection sensor with power supply	1	10456.32	10456.32
Stop bar detectors	Loop intersection stop bar detectors (2 per loop)	2	44521.6	89043.2
Induction loop: Roadway	Roadway sensor with power supply	1	20934.48	20934.48
		UTM Total Cost =		R 8,278,890.08
Incident Management System (IMS)				
IRUs	Toyota Hilux Double Cab (2018 model)	3	326000	978000
MRUs	Toyota Corolla (2018 model)	2	318500	637000
Equipment: Jump bags	Basic life support bags	14	4429.95	62019.3
Equipment: Traffic control	For traffic accommodating and congestion relief	12	8000	96000
LTUs	Tata LTU for lpv and mini van hauling	2	300000	600000
HTUs	Isuzu large towing unit	1	375000	375000
		IMS Total Cost =		R 2,748,019.30
Total cost for hardware, vehicles and equipment associated with TM1 =				R 24,858,314.85

Table 4-11 provides a summary of the costs associated with staff employment and salaries. Salaries were estimated with the aid of SANRAL. Maintenance for the entire Model was chosen as 15% of the initial project cost (hardware, vehicles and equipment cost) and maintenance occurs every two years. This percentage for maintenance was determine via discussions with engineers in the field of Transportation Engineering and was a general percentage mentioned by most parties.

Table 4-11: Costs associated with staff salaries for TM 1

COST BREAKDOWN OF SALARIES ASSOCIATED WITH STAFF (FOR ONE YEAR)				
Staff member	**Duties**	**No. of employees**	**Unit monthly salary (Rand)**	**Annual cost to company (Rand)**
AMS CCTV operators	Monitor AMS CCTV footage and operate VMS	6	10000	720000
TMC Manager	Oversees operations of AMS CCTV operators	1	45000	540000
TMC Assistant Manager	Assists TMC manager in overseeing operations	1	30000	360000
TMC Supervisor	Provides supervision at ground level	1	18500	222000
Urban CCTV operators	Monitor UTM CCTV footage	6	10000	720000
Basic life support paramedics	Offer basic life support to injured persons	6	16171.75	1164366
Flagmen	Secure incident scene and deploy safety signage	12	9500	1368000
Int. life support paramedics	Provide medical response and stabilise patients	2	21432.42	514378
LTU and HTU drivers	Drive vehicles to incident site	3	12000	432000
Traffic software specialists	Manage traffic software associated with TM1	2	19750	474000
Magna TRAFMAN software	Manage and sort traffic data	1 package	---	25000
Total annual cost of salaries for employees =				**R 6,539,744.00**

Finally, Table 4-12 summarises the total cost of TM 1.

Table 4-12: Cost of TM 1

Component	**Cost (Rand)**
Cost of hardware, vehicles and equipment	R24,858,314.85
Annual cost of salaries	R6,539,744.00
Maintenance cost (every two years)	R3,728,747.23
Total project cost after year 1 (excluding maintenance)	**R31,398,058.85**

Costs that were not included in this study include amenities, vehicle fuel, furniture, electricity and further costs not directly associated with setting up TM 1.

Chapter 5: Test Model 2 (TM 2)

Test Model 2 (TM 2) is a system with little infrastructure and relies more on alternative data sources. An intuitive decision was made to determine which components could be reduced for TM 2. The goal of TM 2 is to provide traffic management to Stellenbosch with the same level of functionality as TM 1 at a cheaper cost. The alternative data sources used in TM 2 are Floating Card Data (FCD), as well as visual aid provided by Unmanned Aerial Vehicles (UAVs). The broad changes that are made to TM 1 and a description of how FCD and UAVs are used in the study area are provided in this chapter. The benefits characteristic to TM 2 is discussed in Chapter 6.

5.1 Reduction in equipment and personnel from TM 1

TM 2 consists of a reduced number of CCTV cameras, Vehicle Detection Sensors (VDSs) and urban CCTV cameras. The number of VMS boards are not reduced since traffic information still needs to be conveyed to motorists. Furthermore, Unmanned Aerial Vehicles (UAVs) and Floating Car Data (FCD) are used in cohesion with a central server controlling traffic management practices in TM 2. A reduced number of traffic management components coupled with the use of UAVs and FCD will result in a more cost-effective approach at managing traffic and traffic incidents.

Figure 5-1 shows the reduced hardware from TM 1 that is present in TM 2. TM 2 employs 7 arterial CCTV cameras and 7 VDS devices rather than 25 arterial CCTV cameras and 28 VDSs used in TM 1. Figure 5-2 shows the location of Urban CCTV cameras for Urban Traffic Management (UTM). TM 2 employs 5 urban CCTV cameras rather than 36 CCTV cameras used in TM 1. Table 5-1 shows the updated locations for these components. The cameras were placed so that the FOV of each camera can view the road directly, even when zoomed in fully. Furthermore, cameras were positioned on straight portions of roadways where high speeds occur during off-peak hours so that possible speeding accidents can be picked up. VDSs are co-located with arterial CCTV cameras for design simplicity.

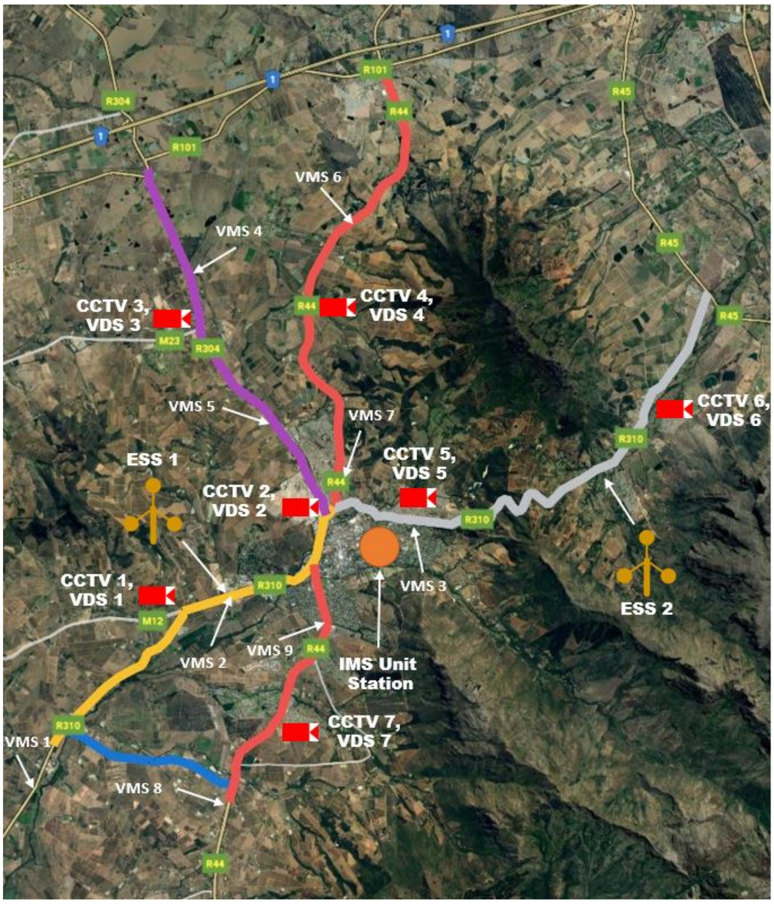

Figure 5-1: Hardware locations for TM 2

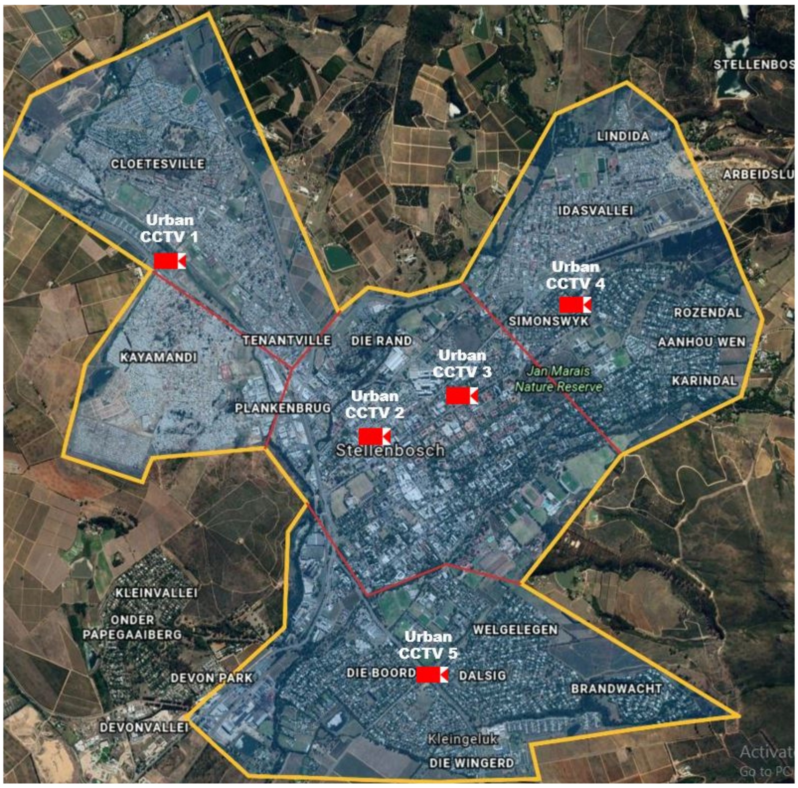

Figure 5-2: Urban CCTV locations

Table 5-1: Location of components for TM 2

Hardware type	Location/At intersection of:
CCTVs: Arterial Management System (AMS) and Vehicle Detection Sensors (VDSs) (roadway VDSs co-located with CCTVs)	
CCTV, VDS 1	R310 and M12 (Polkadraai Road)
CCTV, VDS 2	R310 (Adam Tas Road) and R304 (Bird Street)
CCTV, VDS 3	R304 and M23 (Kromme Rhee Road)
CCTV, VDS 4	R44 and Kromme Rhee Road
CCTV, VDS 5	R310 (Helshoogte Road) and Cluver Road
CCTV, VDS 6	R310 (Helshoogte Road) and Lanquedoc Road
CCTV, VDS 7	R44 and School Road
CCTVs: Urban Traffic Management (UTM)	
Urban CCTV 1	R304 and Mount Simon Drive
Urban CCTV 2	Merriman Avenue and Bird Street
Urban CCTV 3	Merriman Avenue and Bosman Street
Urban CCTV 4	Merriman Avenue and Simonsberg Road
Urban CCTV 5	R44 and Van Reede Road
Variable Message Signs (VMSs)	
VMS 1 to 9	Locations for all VMSs remain the same as in TM 1
Environmental Sensing Stations (ESSs)	
ESS 1	Co-located with VMS 1
ESS 2	R310 (Helshoogte Road) and Swart Street
Incident Management System (IMS)	
Unit Station	Off R310 (Helshoogte Road), close to SAPS garage adjacent to Heidehof Rugby Fields (Current location of Stellenbosch' Fire and Rescue Unit.

The number of AMS CCTV cameras were reduced to seven. Seven VDSs are co-located with these cameras. These cameras are pan-tilt-zoom (PTZ) cameras as in TM 1 and the locations were chosen based on the highest average daily traffic volumes (obtained from Google Maps). These locations are also used by drivers travelling different routes and are main accesses to different neighbourhoods. Furthermore, the reduced functionality of TM 2's CCTV coverage is made up for with the use of UAVs as described in Section 5.3. The same analysis applies to the UTM section only five Urban CCTVs are used. The number of ESSs used were kept the same as in TM 1 since there are limited other methods to determine weather conditions in the study area which is vital for other non-traffic related services as well. Since no alternative information dissemination tool is used in TM 2, the amount and locations of VMSs are the same as in TM 1 since information still needs to be provided to motorists. The adjusted staffing and hardware associated with the AMS is discussed in Section 5.4 which deals with the cost breakdown for TM 2.

Since only seven intersection sensors are used, a reduction in functionality is created since a large portion of the road network is not mapped, resulting in many gaps in the availability of traffic data in the study area. To regain a level of this functionality, the use of probe data corresponding with a central server as described in Section 5.2 is implemented.

A functionality assessment for the IMS, AMS and UTM components of TM 2 is presented in Chapter 6. With the changes made to TM 1, the functionality that components and systems in TM 2 can provide is altered and this functionality assessment is needed to ensure that, although TM 2 is cheaper than TM 1, it still performs acceptably and achieves its traffic management goals.

5.2 Implementation of Floating Car Data (FCD) system

The analysis of data obtained from vehicle probes is used in TM 2 in order to replace functionality after the hardware has been reduced in order to make TM 2 more cost effective than TM 1.

5.2.1 FCD system definition

For the purpose of this study, only vehicular probes is used for data collection. For this study, probe data is obtain from a third-party provider (for example, TomTom®).

Certain assumptions are needed in order to implement FCD to TM 2. These are:

- It is assumed that 5% of vehicles on the roadways of the study area are probes that can transmit location data for analysis.
- Data that is requested is delivered on time.
- The delay associated with data collection from vehicle probes (affected by factors such as vehicle polling frequency, delay associated with data sampling, traffic flow delay and delay associated with data filtering) is not assessed since this step is not important for the purpose of this study.

5.2.2 FCD Incident Detection System (IDS)

The FCD IDS uses location data provided by a third-party supplier such as TomTom® in order to detect incidents. Data is requested for a specific and the dataset provided consists of:

- The date and time period associated with the dataset
- The data source (in this case, vehicle probes)
- The route length covered
- Sample size of vehicles on the roadway for the given time period
- Average travel times and speed, with which percentile travel times and speed can be determined.

The IDS for this study uses the speed, location and time information obtained by probes to determine if an incident has occurred or where traffic is becoming congested. The IDS has three velocity parameters; a lower velocity limit, V_{lower}, upper velocity limit, V_{upper}, and an average velocity placeholder, $V_{average}$. V_{upper} is the free-flow speed that vehicles travel (the speed limit of the road), $V_{average}$ is the average speed that a vehicle travels based on congestion levels at a given time, and V_{lower} is the lowest speed a vehicle can travel at maximum congestion level. These velocities are updated in real-time based on the data received from data probes. When the speed on a road in the study area drops below V_{lower} for a period of time T longer than the average peak congestion time

T_{APCT}, this indicates that an incident has occurred on the particular roadway (T_{APCT} is unique to each roadway for a specific time of day and this is determined from trip generation processes not discussed in this study). This action prompts the VMS to inform drivers to expect delays or to alter their route if they are affected. This action also notifies traffic management staff who can confirm the incident by sending a UAV to inspect the incident scene, as described in Section 5.3 (since the result of congestion may be a faulty traffic signal). Once the speed of vehicles on the roadway increasing to a value above V_{lower}, this indicates that the incident, congestion or accident has been resolved and normal traffic operations are continuing. Locations where drivers break the speed limit V_{upper} can also be identified with the FCD so that measures can be put in place on that particular roadway to prevent reckless driving (since driver identities are not obtained from data probes). This process is illustrated in Figure 5-3.

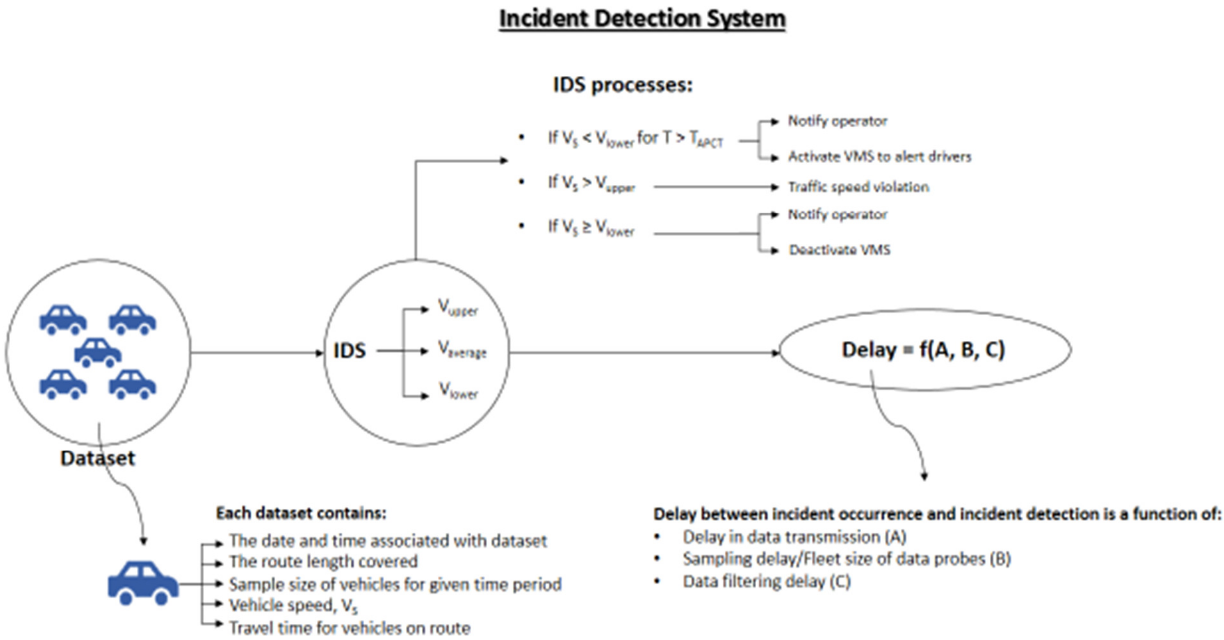

Figure 5-3: IDS

The delay, indicated in Figure 5-3, between when an incident or event leading to traffic congestion occurs and when the data is received is a component of the three factors indicated in Figure 5-3. This delay is a function of the following factors:

5.2.2a) Delay in data transmission (A)

When a data packet is sent to the server, this does not occur instantly. There is a slight delay involved with the transmission of GPS data. This delay is dependent on the specifications of the server system being used and is influenced by connectivity type (server connected via fibre optic cables or ADSL cables), hardware (a server run on a solid-state drive (SSD) works much faster than one run on a conventional hard drive), and software (which programme is being used to manage traffic, overlay GPS coordinates on a live map and receive, aggregate and store data). Additionally, aggregation time of data has a significant impact on delay. This delay is usually in the range of a 20 seconds to a few minutes (Houbraken, et al., 2017). A determination of this delay for Stellenbosch is not conducted in this study.

5.2.2b) Sampling delay (B)
Another delay when receiving data is due to the amount of vehicles that are data probes on the road. FCD usually works with 5% penetration, meaning that 5% of the vehicle population on the road are probes for transmitting location data. Since not every vehicle in the traffic stream is a data probe, the frequency of data transmission is affected and a delay occurs.

5.2.3c) Data filtering delay (C)
Similar to the delay associated with data transmission, there is a delay related to the central server's procedure for filtering data. All datasets that have been misinterpreted, transmitted with errors or that are incomplete are filtered so that usable data is transferred.

5.3 Implementation of UAVs

Unmanned Aerial Vehicles (UAVs/drones) are introduced in Test Model 2 (TM 2) In order to regain a level of the functionality lost after removing hardware, particularly CCTV cameras from TM 1. For this study, UAVs are used for two purposes, namely:

1. To monitor traffic conditions and detect sources of congestion.
2. To verify incident reports and the severity thereof.

5.3.1 UAV used for study and assumptions

The UAV used for this study is the *DJI Inspire 2.* This UAV is owned by the Department of Civil Engineering. Among the various specifications related to this UAV, the most important for this study are:

- Videos can be recorded at up to 6K resolution (6000 pixels of horizontal resolution) at 4.44 Gbps and the camera can pan, tilt and zoom. The gimbal attached for the camera allows the camera to tilt up to 90° in either direction and the camera's field-of-view (FoV) is 55° either side of the camera's view.
- The UAV has a maximum speed of 94 km/h and accelerates from 0 to 80 km/h in five seconds.
- The UAV has two batteries allowing for a maximum flight time of 27 minutes.
- The DJI Inspire 2 can fly in low temperatures since it has self-heating technology.
- The DJI Inspire 2 has obstacle avoidance technology.
- Footage is stored on a Micro-SD Card and is transferred to a Cloud service for storage and data analysis as well.
- The UAV has a controllable range of 7 km from the controller (DJI, 2020).

In order for this study to be completed, certain assumptions relating to UAVs needed to be made. These assumptions allowed for a theoretical procedure of analysis and are:

- Obstructions and interferences that may affect the controllable range of the UAV were not determined and it is assumed that the controllable range is true for any location in the study area.
- Effects of changing video quality and other UAV options on the battery life of UAV was not considered and 27 minutes is used as the maximum operating time for the UAVs based on the maximum flight time provided by the batteries of the UAV.
- All UAVs used in study can fly to the height required and are kept within commercial height regulations as constructed by The South African Civil Aviation Authority (SACAA).

- All UAV operators are capable of avoiding obstacles and the time it takes to avoid obstacles was not used in assessments which are time-constrained.

The DJI Inspire 2 is shown in Figure 5-4.

Figure 5-4: DJI Inspire 2 (Prindle, 2018)

5.3.2 Traffic monitoring

Due to the decreased amount of CCTV cameras in TM 2, the video surveillance functionality of TM 2 is reduced since a large portion of the study area's roadways are not monitored. For TM 2, UAVs are used to monitor traffic conditions. An advantage of the UAV is its mobility and ability to view roads from above. This allows areas not covered by CCTVs to be monitored. There are, however, four issues, which are:

- Determining areas that require monitoring the most, since not all the areas in the study area can be covered
- The limited battery life of the UAV
- Determining an appropriate height to fly the UAV so that video footage is clear
- Regulations of no-fly zones that may affect flight patterns of the UAV

5.3.2a) UAV count, coverage period and operations base location

Due to the limited battery life associated with the UAV, it was decided that the morning and afternoon peak 2-hour periods were to be assessed (06h00 – 08h00 and 16h00 – 18h00). These periods were chosen based off Google Maps' colour-coded heat map representing daily traffic conditions which shows peaks based on lowest speeds. For management of sporting and other events that attract high vehicle volumes, UAVs are also used.

Since the maximum battery life of the DJI Inspire 2 is 27 minutes, four UAVs (with two operators; one for the morning peak period monitoring and one for the afternoon peak) are used for traffic monitoring. Within the 2-hour peak periods, the heat maps from Google were assessed and it was found that from 06h00 until 06h20 traffic volume was the lowest in the morning peak. For consistency, the lowest traffic volume 20 minute period in the afternoon 2-hour peak is 16h00 – 16h20. The UAVs are therefore sent out for 25 minute periods as indicated in Table 5-2. This allows for a 2 minute buffer to switch to the next UAV for the next time period.. UAVs are charged between morning and afternoon peaks, and again once the afternoon monitoring process is completed.

Table 5-2: UAV operating times

UAV number	AM operating time	PM operating time
1	06h20 – 06h45	16h20 – 16h45
2	06h45 – 07h10	16h45 – 17h10
3	07h10 – 07h35	17h10 – 17h35
4	07h35 – 08h00	17h35 – 18h00

Furthermore, to avoid the cost of constructing a location solely for UAV deployment, UAVs are stored at and deployed from the IMS Unit Station close to the SAPS garage off the R310 (Helshoogte Road). UAVs can therefore travel a maximum distance of 7 km from the base station. This is a good location because peak traffic volumes and high congestion are experienced within this 7 km radius. The Incident Detection System (IDS) is used throughout the entire study area and monitors the road network outside of the UAVs' coverage.

5.3.2b) UAV deployment procedure

In order to monitor the entire study area, the UAVs follow a specified path at a specific height above the ground travelling at a pre-determined speed. Determining the height the UAV would operate depends on its image quality. Since the DJI Inspire 2 has a good camera relative to most UAVs, the height of flight is chosen as 120 metres. Figure 5-5 shows the quality of the DJI Inspire 2 at a height of 400 feet (122 m).

Figure 5-5: DJI Inspire 2 image quality at 122 metres (Dronegenuity, 2018)

Each UAV flies the same path throughout the study area. This is to ensure that no specific area is left unmonitored for a longer period of time than any other area. Although certain UAVs have pre-set path settings which allows for autonomous flying, a UAV pilot will operate the drone in case any unexpected issues arise.

The UAV was chosen to fly at 120 metres above the ground. Following this, the angle, Θ, at which the camera's FoV is set static, was chosen as Θ = 50°. This means that the FoV of the footage is cut-off at 50° to the left and 50° to the right, therefore a total FoV of 100° (as opposed to the maximum of 110°) is chosen for the camera. 5° Was chosen to be cut off of the FoV so that the edge view of the UAV is as clear as the centre view, where the UAV faces down. Since the UAV flies 120 metres above the ground and Θ = 50°, a Pythagorean relationship is used to determine the distance, X, in the camera's FoV, which is

$$tan\Theta = \frac{X}{120}, \therefore X = 120 * \tan(50°) = 143\, metres$$

The camera sees 143 metres either side of its centre point above the ground, therefore

$$Total\ FoV = 143 * 2 = 286\, metres$$

Figure 5-6 is a basic illustration to aid the determination of the FoV.

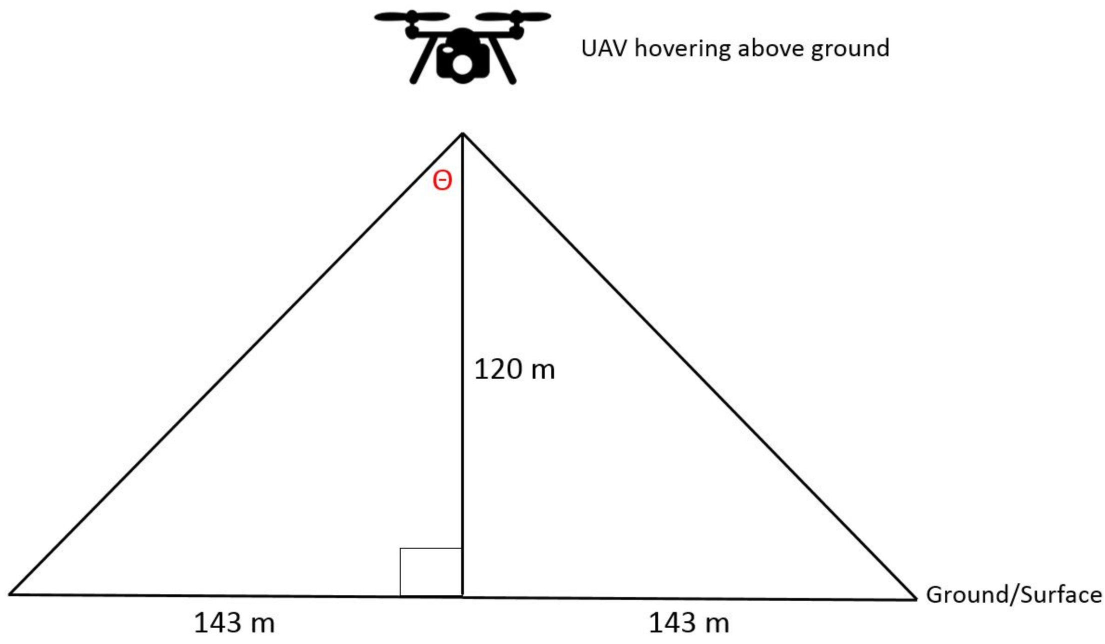

Figure 5-6: FoV determination for study area

Following this, the route and speed at which the UAVs fly during the peak periods are required. A 4 km radius around the UAV deployment location was chosen as the area of coverage for monitoring the morning and afternoon peaks. This is where the highest traffic volume and congestion levels occur (Central Stellenbosch). The route that the UAVs follow is based on the 4 km radius from the deployment station as can be seen in Figure 5-7 (radius indicator is cut off so that image quality can be higher).

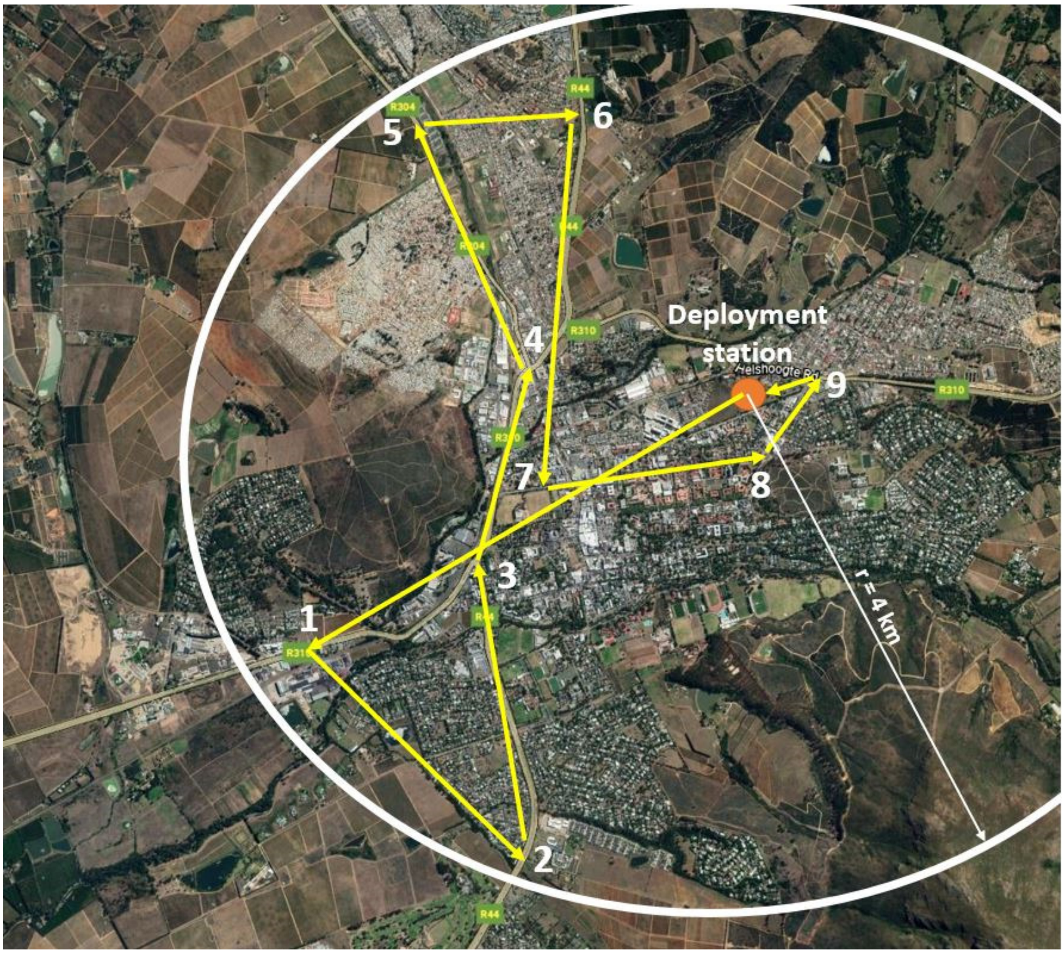

Figure 5-7: UAV path (↑N)

Table 5-3 provides details of the path the UAVs follow during the traffic monitoring process shown in Figure 5-7. The map identifiers (labelled 1 to 9) on Figure 5-7 are used to explain the path, starting and ending at the deployment station (DS).

Table 5-3: UAV path details

Identifier route	Start location/intersection of	End location/intersection of	Distance (km)
DS – 1	Deployment station	R310 (Adam Tas Road) + Oude Libertas Road	3.94
1 – 2	R310 (Adam Tas Road) + Oude Libertas Road	R44 (Strand Road) + Trumali Street	2.12
2 – 3	R44 (Strand Road) + Trumali Street	R310 (Adam Tas Road) + R44	2.19
3 – 4	R310 (Adam Tas Road) + R44	R310 (Adam Tas Road) + R304	1.44
4 – 5	R310 (Adam Tas Road) + R304	Unnamed road leading to Jolly Tots Farm	1.93

5 – 6	Unnamed road leading to Jolly Tots Farm	R44 + Ortell Road	1.20
6 – 7	R44 + Ortell Road	Merriman Avenue + Hofman Road	2.78
7 – 8	Merriman Avenue + Hofman Road	Merriman Avenue + Marais Road circle	1.65
8 – 9	Merriman Avenue + Marais Road circle	R310 (Helshoogte Road) + Cluver Road	0.674
9 – DS	R310 (Helshoogte Road) + Cluver Road	Deployment station	0.506
Total UAV flight distance =			**18.43 km**

Finally, since the UAV flight distance is known, the speed at which the UAVs fly can be determined. With a 25 minute (0.4167 hour) flight period for a total distance of 18.43 km, the speed of the UAVs are set at

$$UAV\ speed = \frac{distance}{time} = \frac{18.43}{0.4167} = 44.2\frac{km}{h}, use\ 45\frac{km}{h}$$

This is a good, steady speed which allows the UAV operator to have more time to pick up any incidents related to traffic flow. This speed also gives the UAVs more time to process images and lessens the possibility of transferring erroneous data to the Cloud.

5.3.3 UAV aiding Incident response

For TM 2, the incident management process is aided with the use of UAVs. Functionality relating to incident response time is lost in TM 2 with the decision of reducing the number of staff and response units as indicated in Section 5.1. With an increased delay associated the IDS through the implementation of FCD (as opposed to TM 1's extensive CCTV camera coverage), the time it takes for an incident to be detected is increased. To give value to the use of UAVs in incident response, the following reasons are provided:

- UAVs are sent out to inspect incident sites to justify the accuracy of incident reports.
- UAVs are used to lessen the difficulty of on-scene manoeuvrability that response units experience by providing information from an overhead view.
- UAVs are used to improve the safety of on-site responders by providing information regarding possible hazardous environments (such as an oil spill, for example) and by

providing enhanced imagery to the responder to aid in the preparation of incident clearance.

5.3.3a) Components needed for incident response

For the implementation of UAVs, a UAV Incident Unit (UAVIU) is needed, which consists of:

- A UAV and digital imaging payload – the UAV used is the DJI Inspire 2. This UAV is not one of the four UAVs used in traffic monitoring. The imaging payload is the 6K camera attached to the UAV.
- Sensor payloads – sensor payloads such as infrared and Light Detection and Ranging (LIDAR) are required to aid the UAV pilot to map an incident scene. This software is available with the DJI Inspire 2. An analysis of how this software is configured for incident management is not provided in this study since this is a broad topic with various different aspects that need to be analysed. It is assumed that the UAV has the appropriate payloads and settings pre-set.
- UAV Response Unit (UAVRU) – a vehicle to transport the UAV and pilot to an incident site if the incident occurs more than 7 km from the Unit Station (>max controllable distance from controller). A 2018 Toyota Hilux single cab is used in this study.
- UAV ground control station – a laptop for navigational control and to analyse data obtained from processed images.
- Two-way communication – equipment that allows the UAVIU crew on site to communicate with operators at the Unit Station to transfer information relating to the severity of the incident and which crew needs to be sent out. The UAVIU uses the conventional radio used by paramedics.
- Data communication infrastructure – equipment that allows the UAVIU to transmit data in real-time to the operators at the Unit Station. In this study, it is assumed that the footage observed by the UAV pilot at the incident scene is transmitted in real-time to the Unit Station through display mirroring software associated with the laptop.

5.3.3b) Incident response process

For incidents that occur within the UAV’s 7 km controllability range of the Unit Station where UAVs are stored, the UAVs are deployed from the Unit Station. For incidents that occur outside this range, the UAVIU is deployed to the scene. Figure 5-8 indicates the procedure followed for incidents occurring beyond the 7 km range.

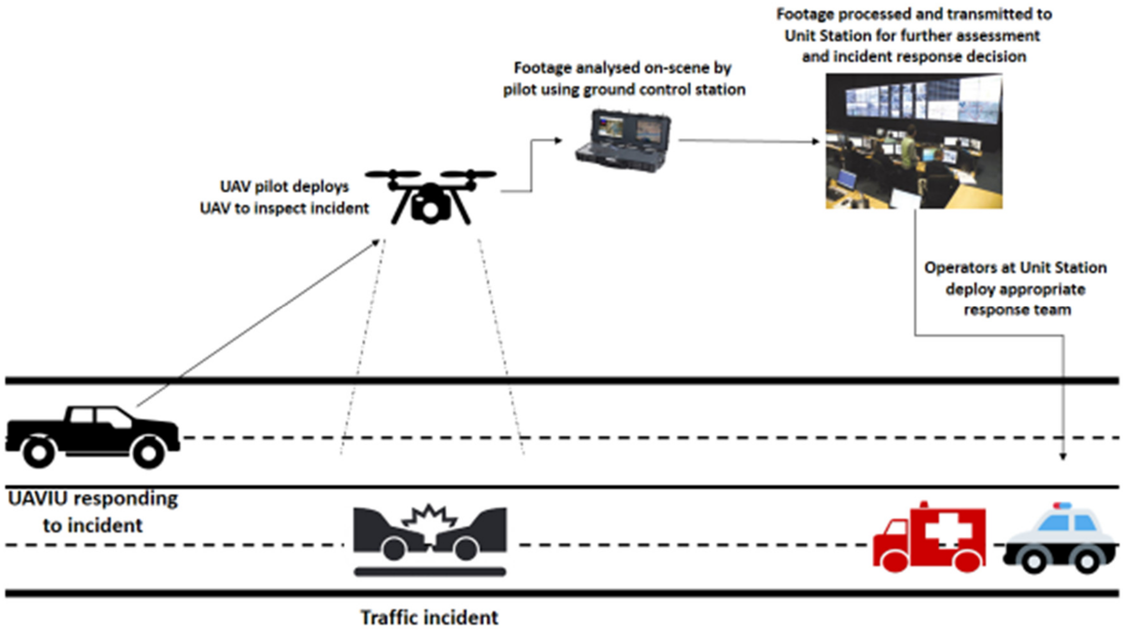

Figure 5-8: Incident response procedure for UAVs. (Hi-Tech Security Solutions, 2013), (Alpha Unmanned Systems, 2020) – references for images used in Figure.

The steps related to Figure 5-8 are as follows:

1. Notification that an incident has occurred is received by operators at the Unit Station.
2. The UAVIU is deployed to the incident scene for inspection for incidents further than 7 km away from the Unit Station. For incidents within a 7 km range of the Unit Station, the UAV is deployed from the Station.
3. The UAVIU pilot launches the UAV which is loaded with digital image processing and sensory payloads.
4. The UAV is flown to assess the incident scene and transmits this data in real-time high-definition video format to the on-scene ground station.
5. The ground station transmits this data to the Unit Station for assessment.
6. Depending on the situation, the UAV pilot may give camera control (allowing camera to pan, tilt and zoom) to the Unit Station operators to aid assessment at the Unit Station. The UAV is always fully controlled by the pilot.
7. Depending on the severity of the incident scene and the time it takes to assess, the UAV can be returned to the pilot for a battery change.
8. Once the relevant decisions are made by the operators at the Unit Station, the UAVIU departs from the incident scene.

Compared to the incident management process in TM 1, TM 2's incident management process is almost exactly the same. The only difference in TM 2 is that the incident is confirmed with the UAVIU.

The time it takes for the UAV to be deployed from the Unit Station or UAVIU to arrive at the incident scene affects the arrival time of response units to the scene. This is in the range of a few minutes and has a big impact on incident clearance and response, since a few minutes is vital in a near-fatal situation. It was therefore decided that one basic life support paramedic accompany the UAVIU in case the aforementioned near-fatal incident occurs. Furthermore, for incidents occurring within the 7 km radius of the Unit Station, the UAV is flown at its maximum speed of 94 km/h. The longest an incident occurring within this 7 km radius will be extended by occurs when an incident is exactly 7 km away from the Unit Station. The UAV arrives at such a scene after $s = \frac{d}{t}, \therefore t = \frac{d}{s} = \frac{7}{94} =$ 4.5 minutes. The functionality affected in the incident management procedure is assessed in Chapter 6.

5.4 Cost breakdown for TM 2

The costs associated with TM 2 are described in this Section. The specifications of hardware and equipment used in TM 2 are the same as in TM 1 since the same type of CCTV cameras, operator workstations, video sensing equipment, weather stations and emergency response equipment are used. Changes to quantities of components are indicated in the cost summary provided in Table 5-4. This section highlights the changes made from TM 1. The equipment not present in TM 1 includes:

- **UAVs**: The DJI Inspire 2 Quadcopter UAV is used in TM 2. The UAV comes with a remote and its specifications have been provided in Section 5.3.1.The unit cost of this UAV + remote is R156,662.00 (PC Link Shop, 2020).
- **UAV batteries**: In the event of a UAV's battery dying or any other unexpected malfunction occurs with the batteries of any of the UAVs, spare batteries are available. The batteries have a 4280 mAh capacity and provide a voltage of 22.8 Volts. The unit cost of a battery is R6,417.50 (Import It All, 2020).
- **UAV Battery case**: When a UAV is needed to inspect an incident scene, this waterproof, air tight and dustproof holder is used. The CasePro battery case has a custom high density foam for added protection. The unit cost of the battery case is R5,907.00 (PC Link Shop, 2020). It is important to note that the cost of a UAV ground station (a laptop to view UAV footage on at an incident scene) is included in this price.
- **UAV Battery charger**: Since UAV batteries run out in short periods of time, a multi-port battery charger is required as opposed to singular battery chargers. The DJI Inspire 2 Intelligent Flight battery charging hub is therefore used that can charge 4 batteries simultaneously. The unit cost of the battery charger is R2,499.00 (Geewiz, 2020).
- **UAV pilot**: A South Africa Civil Aviation Authority (SACAA) qualified Remote Piloted Aircraft System (RPAS) pilot is needed to fly the UAV for traffic management purposes. Since there are no sources that indicate a fixed income for these pilots (since UAVs are generally new to South Africa), the pilot will be paid a salary of R20,000.00 per month.
- **FCD software**: Various suppliers of FCD are present in South Africa. For this study, TomTom® is chosen as the FCD provider since they already provide FCD to the University Of Stellenbosch. The yearly cost of a subscription to TomTom's packages and services is chosen as R1,000,000.00. A variety of cost estimates for a yearly subscription of TomTom data were provided but all these estimates differed depending on the specific type of data required for the company reviewed. From discussions with professionals using TomTom data, the cost quoted was in the order of R1 million, and this value is used for this study.

- **FCD software specialist**: An employer who is familiar with FCD is required for FCD management. It is assumed that the traffic management software specialists used in TM 1 are capable of doing this, and these specialists earn R19,750.00 as in TM 1.

Table 5-4 provides a summary of the costs associated with setting up TM 2 and its associated hardware, vehicles and equipment. It is important to note that an extra vehicle is not provided for the UAVIU as one of the vehicles from the other IMS divisions will be used. Furthermore, the same UAV pilot will respond to incidents using the UAVIU.

Table 5-4: Summary of cost of hardware, vehicles and equipment for TM 2

COST BREAKDOWN FOR COMPONENTS OF TM2				
Arterial Management System (AMS)				
Component	**Description**	**Quantity**	**Unit Cost (Rand)**	**Cost (Rand)**
CCTV cameras	PTZ 2MP high def cameras	7	200371.3	1402598.96
CCTV workstations	PC and accessories	1	42894.11	42894.11
VMSs	Overhead message sign	9	581620	5234580
Intersection VDSs	Infrared video sensing equipment	7	105010	735070
ESS	Wireless weather station with data logger	2	163985	327970
Server processor	Intel Xeon 5130 2.0GHz/4MB processor	1	74585	74585
Server room HDDs	500GB standard SATA hard drive	4	906	3624
Outstation	Station for data collection and TM assessment	1	155296.3	155296.25
		AMS Total cost =		**R 7,976,618.32**
Urban Traffic Management (UTM)				
CCTV cameras	PTZ 2MP high def cameras	5	200371.3	1001856.4
		UTM Total Cost =		**R 1,001,856.40**
Incident Management System (IMS)				
IRUs	Toyota Hilux Double Cab (2018 model)	3	326000	978000
MRUs	Toyota Corolla (2018 model)	2	318500	637000
Equipment: Jump bags	Basic life support bags	14	4429.95	62019.3
Equipment: Traffic control	For traffic accommodating and congestion relief	12	8000	96000
LTUs	Tata LTU for lpv and mini van hauling	2	300000	600000
HTUs	Isuzu large towing unit	1	375000	375000
		IMS Total Cost =		**R 2,748,019.30**
Unmanned Aerial Vehicle (UAV) System				
UAVs	DJI Inspire 2 Quadcopter UAV + remote	5	152662	763310
UAV batteries	DJI TB50 4280mAh spare batteries	4	6417.5	25670
Battery case	CasePro Inspire 2 battery case	1	5907	5907
Battery charger	Intelligent Flight 4-unit charger	1	2499	2499
		UAV Total Cost =		**R 797,386.00**
Total cost for hardware, vehicles and equipment associated with TM2 =				**R 12,523,880.02**

Table 5-5 provides a summary of the costs associated with staff employment and salaries. Salaries were estimated with the aid of SANRAL. Maintenance for the entire Model was chosen as 15%, as for TM 1, of the initial project cost (hardware, vehicles and equipment cost) and maintenance occurs every two years.

Table 5-5: Costs associated with staff salaries for TM 2

COST BREAKDOWN OF SALARIES ASSOCIATED WITH STAFF (FOR ONE YEAR)				
Staff member	Duties	No. of employees	Unit monthly salary (Rand)	Annual cost to company (Rand)
AMS CCTV operators	Monitor AMS CCTV footage and operate VMS	6	10000	720000
TMC Manager	Oversees operations of AMS CCTV operators	1	45000	540000
TMC Assistant Manager	Assists TMC manager in overseeing operations	1	30000	360000
TMC Supervisor	Provides supervision at ground level	1	18500	222000
Urban CCTV operators	Monitor UTM CCTV footage	3	10000	360000
Basic life support paramedics	Offer basic life support to injured persons	6	16171.75	1164366
Flagmen	Secure incident scene and deploy safety signage	12	9500	1368000
Int. life support paramedics	Provide medical response and stabilise patients	2	21432.42	514378
LTU and HTU drivers	Drive vehicles to incident site	3	12000	432000
Traffic software specialists	Manage traffic software and FCD	2	19750	474000
UAV Pilot	SACAA RPAS qualified pilot	1	20000	240000
Magna TRAFMAN software	Manage and sort traffic data	1 package	---	25000
TomTom FCD package	Yearly TomTom FCD package subscription	1 package	---	1000000
Total annual cost of salaries for employees =				R 7,419,744.00

Finally, Table 5-6 summarises the total cost of TM 2.

Table 5-6: Cost of TM 2

Component	Cost (Rand)
Cost of hardware, vehicles and equipment	R12,523,880.02
Annual cost of salaries	R7,419,744.00
Maintenance cost (every two years)	R1,878,582.00
Total project cost after year 1 (excluding maintenance)	**R19,943,624.02**

Again, costs that were not included in this study include amenities, vehicle fuel, furniture, electricity and further costs not directly associated with setting up TM 2.

Chapter 6: Functionality Assessment

The functionality (how well the system works) provided by Test Models 1 and 2 are assessed in Chapter 6. This chapter compares the functionality provided by selected components from TM 1 and TM 2 and assesses the benefits and limitations associated with these components. The goal of Chapter 6 is to determine if TM 2 is a suitable, cost-effective alternative method to manage traffic as compared to TM 1.

Firstly, the amount of functionality lost due to reducing the hardware in TM 2 needs to be determined based on the functionality provided by TM 2. Following this, the amount of functionality regained by implementing the use of UAVs and FCD is determined. The difference in functionality between TM 1 and TM 2 is then compared, based on the sections to follow, which include:

1. An assessment of the functionality provided by hardware and components between TM 1 and TM 2.
2. An assessment of the incident response time from the IMS Unit Station.
3. A comparison of vehicle detection between VDSs and FCD.
4. An assessment of the traffic management capability of a UAV system.
5. An assessment of the delay in incident response.

Following this, an economic evaluation for TM 1 and TM 2 is provided, which assesses the life cycle costs associated with each TM.

6.1 Functionality of TM 1 and TM 2 hardware

As a starting point in comparing the effectiveness of TM 2 to TM 1, the functionality of the hardware and equipment for both TMs are assessed. The components for both TMs are assessed based on the amount of coverage provided, which is used as a basis for comparison. The following components are therefore not assessed in this Section since they appear equally in both TMs which thus provides the same coverage and do not need to be assessed (since this chapter aims to assess the differences between the two TMs):

- **VMSs** – Both TM 1 and TM 2 have 9 VMS boards since traffic information needs to be provided and alternative data dissemination methods are not explored in this study.
- **ESSs** – Weather and environmental information needs to be as accurate as possible and strong winds on the northern portion of the R310 (Helshoogte Road) would cause weather information to be slightly inaccurate for the central and south-western parts of the study area if only one ESS is used.
- **IMS** – The location and number of response units for incident response is kept the same for both TMs 1 and 2 due to Stellenbosch being a small city as compared to larger cities such as Cape Town, therefore only requiring a limited number of incident response personnel.

The hardware quantities that differ between TM 1 and TM 2 are the number of CCTV cameras and Vehicle Detection Sensors (VDSs) (including the absence of the two induction loops used in Urban Traffic Management).

6.1.1 TM 1 AMS CCTV coverage

To compare the difference in CCTV coverage provided between TM 1 and 2, the field of view (FOV) of one camera needs to be determined. To avoid repetition of images, Figures 4-2 to 4-5 representing the placement of CCTV cameras in Section 4.1.2b are referred to here. Figure 6-1 indicates the FOV of one CCTV camera.

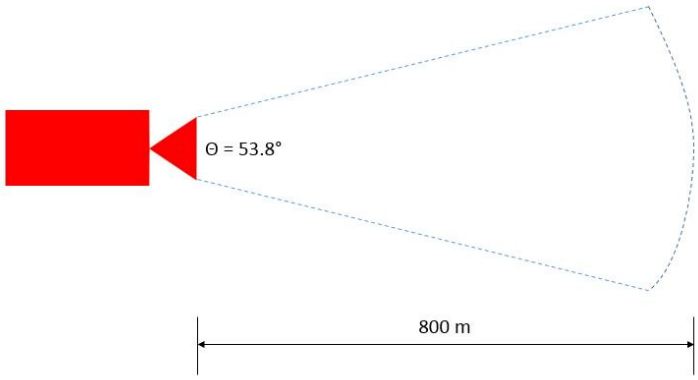

Figure 6-1: CCTV FOV

From Figures 4-2 to 4-5 and the CCTV FOV coverage shown in Figure 6-1:

- The CCTVs on the eight Roadways are all spaced in such a way that they are at least 1 km away from each other. The only exception are the CCTVs at the R310 (Adam Tas Road) / R304 (Bird Street) intersection and the R310 (Adam Tas Road) / R310 (Helshoogte Road) intersection, where these CCTVs are 350 m apart (necessary for line of sight issues, height changes and the intersections being key traffic congestion points).
- The Adam Tas / R304 camera faces the direction of Adam Tas Road northbound and the camera at the Adam Tas / Helshoogte intersection faces Helshoogte Road Outbound, thus the spacing between these two cameras is acceptable.
- All cameras are positioned in such a way as to have 800 m of roadway within its FOV. The only exception is the Adam Tas – R304 camera, which has 350 m of roadway in its FOV.
- All cameras can rotate since these are pan-tilt-zoom (PTZ) cameras, but the cameras itself remain static until an operator rotates them.

From this, Table 6-1 indicates the amount of arterial roadway clearly (in 800 m vision) covered by the cameras for TM 1. Note that although Roadway 4 has two cameras, only one faces the direction of Roadway 4. The second camera faces Helshoogte Road Outbound. Table 6-1 also indicates the longest length of each route not covered by CCTV cameras (the longest portion of road between cameras that is in view of CCTV cameras).

Table 6-1: Amount of arterial roadway clearly covered with CCTV cameras for TM 1

Route	Map Identifier no.	Roadway length (km)	Amount of roadway covered by CCTV	%Roadway covered	Longest length not covered (km)
R310	Roadway 1	5.16	3*800 m = 2.4 km	46.5	1.14
R310	Roadway 2	4.25	1*800 m = 0.8 km	18.8	2.65
R310	Roadway 3	1.46	1*800 m = 0.8 km	54.8	0.66
R310	Roadway 4	0.345	1*345 m = 0.345 km	100	0
Helshoogte Road	Roadway 5	15.74	8*800 m = 6.4 km	40.7	3.35
R304	Roadway 6	11.67	4*800 m = 3.2 km	27.4	2.57
R44	Roadway 7	14.87	4*800 m = 3.2 km	21.5	2.73
R44	Roadway 8	7.64	3*800 m = 2.4 km	31.4	3.22
Total		**61.14 km**	**19.55 km**	**32%**	

Although a total coverage of 32% of the total arterial network might seem low initially, this is justifiable in terms of cost and functionality. Overloading the system with CCTVs to provide 100% coverage would be extremely expensive to implement and maintain. The cameras used in this study are able to zoom and rotate if need be, providing good focus in the full range of coverage. Furthermore, these cameras were placed based on the speed profiles available on Google Maps. The cameras were placed at intersections and on the portions of the roadways that experienced lower traffic speeds due to traffic congestion and are therefore more likely to experience traffic incidents. This strategic placement of cameras allowed for the number of cameras on arterials to be limited to 25 cameras, which is an acceptable number of cameras to provide coverage of a sufficient percentage of the roadways in Stellenbosch.

The central portion of Stellenbosch on Roadway 4, which experiences the worst amount of traffic congestion during the morning and afternoon peak periods as compared to any other roadway in the study area, is fully covered. The cameras on Roadways 1 and 3 are strategically placed to ensure that the portions of these roadways where incidents are more likely to occur are covered, and the percentage of these two roadways covered is relatively high compared to the other roadways since they experience a large outflow of traffic in the afternoon peak period. If an incident occurs on the road segments that are not covered by CCTV, it is assumed that queued vehicles will become clear soon after the incident allowing adequate incident detection to take place

6.1.2 TM 2 AMS CCTV coverage

TM 2 consists of a considerably fewer number of CCTV cameras, as indicated on Figure 5-1 in Section 5.1. Table 6-2 provides the amount of arterials clearly covered in TM 2 by CCTV cameras.

Table 6-2: Amount of arterial roadway clearly covered with CCTV cameras for TM 2

Route	Map Identifier no.	Roadway length (km)	Amount of roadway covered by CCTV	%Roadway covered	Longest length not covered (km)
R310	Roadway 1	5.16	0	0	5.16
R310	Roadway 2	4.25	1*800 m = 0.8 km	18.8	3.45
R310	Roadway 3	1.46	0	0	1.46
R310	Roadway 4	0.345	1*345 m = 0.345 km	100	0
Helshoogte Road	Roadway 5	15.74	2*800 m = 1.6 km	10.2	9.2
R304	Roadway 6	11.67	1*800 m = 0.8 km	6.9	5.71
R44	Roadway 7	14.87	1*800 m = 0.8 km	5.4	10.87
R44	Roadway 8	7.64	1*800 m = 0.8 km	10.5	6.84
Total		**61.14 km**	**5.145 km**	**8.4%**	

From Table 6-2:

- A total of only 5.145 km of the arterial network is monitored by CCTV cameras in TM 2, as compared to 19.55 km in TM 1.
- Since a lower percentage of roadway is covered in TM 2, the functionality of TM 2's video surveillance is lessened. In order to obtain this lost functionality, FCD is used in TM 2 to aid traffic observations as described in Section 6.3.
- The use of UAVs in TM 2 for traffic management also aids in regaining TM 2's loss of traffic management capacity and this is evaluated in Section 6.4.
- Comparing Tables 6-1 and 6-2, it is evident that a larger portion of road for the Roadways are not covered in TM 2 as in TM 1 due to the reduced number of cameras.

6.1.3 Urban CCTV cameras

The same analysis conducted for CCTV cameras for the AMS can be done for the urban CCTV cameras used. However, this analysis is not done since only five CCTV cameras are used throughout the entire urban area and a good comparison of the effectiveness of Urban CCTVs for TM 1 and TM 2 cannot be obtained using the analysis method for AMS CCTV cameras. Since UAVs and FCD are used in TM 2, the combination of these two systems are assessed to determine the functionality they can provide to TM 2.

In TM 1, there are 36 Urban CCTV cameras and in TM 2 there are five. There is a great reduction in camera coverage between the two TMs. The purpose of the CCTV cameras in the urban areas are mainly for security and surveillance. Traffic management occurs mainly on arterials. Furthermore, the FCD and UAVs used in TM 2 are assessed and their functionality is analysed and discussed in Sections 6.2, 6.4 and 6.5. The same analysis done for the AMS's CCTV cameras is therefore not conducted here.

6.1.4 VDS coverage

The reason VDSs are used in addition to FCD is because they provide traffic volume information. FCD cannot provide traffic volume information which means that VDS and FCD datasets are not equivalent. VDSs are used for traffic monitoring rather than for incident detection.

The number of VDSs differ significantly between TM 1 and TM 2. There are two ways how the functionality provided by VDSs can be tested by determining what vehicle information is obtained by each VDS and what information is lost due to the absence of VDSs at specific locations. This is done through aggregated Origin-Destination (OD) information being obtained and driver locations being mapped on the road network using FCD.

Since this method is time consuming and a large amount of FCD is required, a simpler method is followed in this study. A route analysis for the arterials is conducted. The coverage provided for both TMs can therefore be assessed directly. TM 1 has 28 VDS and TM 2 has 7. Furthermore, TM 2 does not have VDSs on the road segments as TM 1 does, only at intersections. This reduces the amount of VDS information obtained by TM 2 and this is attempted to be regained with the use of FCD. Table 6-3 provides a comparison of the number of VDSs between TM 1 and TM 2.

Table 6-3: VDS comparison

Route	Map Identifier no.	TM 1	TM 2
R310	Roadway 1	3	0
R310	Roadway 2	3	1
R310	Roadway 3	3	0
R310	Roadway 4	2	1
Helshoogte Road	Roadway 5	4	2
R304	Roadway 6	6	1
R44	Roadway 7	4	1
R44	Roadway 8	3	1
Total		**28**	**7**

From Table 6-3, all eight roadways have fewer amount of VDSs in TM 2. The reason these VDSs were shifted was to be co-located with CCTV cameras to avoid extra costs and to be placed strategically where vehicle traffic is prevalent to obtain traffic data. FCD is used in TM 2 which aims to provide the necessary traffic data to traffic management operators in order for any incident, event or traffic condition to be managed. Roadway 5 has two VDSs since Helshoogte Road is longer than the other routes.

6.1.5 Comparison of hardware and components

Table 6-4 provides a summary of the coverage of the study area in TM 1 and TM 2.

Table 6-4: Study area coverage

Test Model	% CCTV coverage	Number of VDSs
TM 1	32%	28
TM 2	8.4%	7
Difference	**23.6%**	**21**

6.2 Testing of incident response time from Unit Station

According to Seaman (2017), the average response time for incident management to any incident scene should be under 15 minutes. This response time is based on traffic conditions of the area under analysis and it holds for all areas within an emergency response team's jurisdiction.

In order to support the decision for the location of the IMS Unit Station in this study, FCD is used to assess the emergency response time from the Unit Station to any location within the study area. The goal of analysing the FCD is to determine what the travel time is for a response vehicle travelling from the Unit Station to any point along the arterials of the study area, and how much this deviates from 15 minutes. FCD provided by TomTom® using the TomTom Move® platform was used in this analysis.

6.2.1 Dates and times of analyses

The data used for the FCD analysis were collected on weekdays of October 2019 (1 to 31 October). This month was used for analysis for the following reasons:

- Months during the year 2020 were ruled out due to the lockdown implemented because of the COVID-19 pandemic, where various travel restrictions were in place and many people worked from home. 2019 was chosen since it is the most recent year and vehicle population, car statistics and other statistics related to time would be as close to recent as possible.
- October was chosen as it was a month with no school and university holidays and also no public holidays. This was to ensure that the traffic data obtained is not affected by these holidays and that each day assessed would be a true representation of how traffic generally is on that day for October. Furthermore, weekends were not analysed since traffic in the week would be worst and the analysis requires the worst case scenario traffic as a design principle (design for the worst conditions).
- Times were analysed in one hour intervals, with the base set being from 23h00 to 05h00. This time interval was chosen as the base set since the traffic is the least during this period of the day. Furthermore, the peak periods which are analysed in this report are the morning peak, 07h00 – 09h00, and the afternoon peak, 16h00 – 18h00. These were the time periods with the highest travel times from the Unit Station to the end point of the arterials in the study area.

6.2.2 Types of analyses conducted

Two types of analysis were conducted for this study: a route analysis and an area analysis. Route analyses assessed travel times along the arterials of the study area and provided information relating to travel times and speeds for the different time intervals travelling from the Unit Station to the end points of the arterials. Route analyses were also conducted for the response teams that could possibly be located on the R310 (Adam Tas Road) just north of the Molteno Road / Adam Tas Road intersection. The route analysis is provided as an Excel spreadsheet. Furthermore, an area analysis for the entire study area was conducted which provides information relating to speed and travel time for all roads in class ranges 0 – 6 for the study area. The area analysis is provided as a kmz file which opens on any software supporting map viewing. It is important to note that the response units are referred to as a collective, which means that separate speed and travel time analyses have not been conducted for LTUs and HTUs.

6.2.3 Overview of results of FCD incident response analysis

Table 6-5 summarises the results of the FCD analysis for the different arterials for the base set, morning peak and afternoon peak. The peaks are split up in one hour intervals. The start point for the analyses is the IMS Unit Station. This start point was set up from the Cluver Street / Helshoogte Road intersection since the distance from the Unit Station's garage to this intersection provides a negligible time interval. Northbound (NB) and southbound (SB) routes were assessed. Note that in Table 6-5, only the peak AM and PM one hour periods are provided.

Table 6-5: Summary of results for base set, morning and afternoon peaks from Cluver – Helshoogte start point

Route followed	Route end intersection	Covered road length (kilometre)	Time set (hour)	Average travel time (HH:MM:SS)	Average speed, harmonised (km/h)
R44 NB	R101 (Old Paarl Road)	16.906	Base Set	00:13:31	75.06
			AM Peak (7 – 8 am)	00:16:13	62.55
			AM Peak (8 – 9 am)	00:15:30	65.45
			PM Peak (4 – 5 pm)	00:19:49	51.20
			PM Peak (5 – 6 pm)	00:20:45	48.87
R44 SB	Annandale Road	11.510	Base Set	00:15:08	63.67
			AM Peak (7 – 8 am)	00:17:59	35.01
			AM Peak (8 – 9 am)	00:16:30	39.03
			PM Peak (4 – 5 pm)	00:20:36	30.42
			PM Peak (5 – 6 pm)	00:17:48	34.82
R304 NB	R101 (Old Paarl Road)	14.710	Base Set	00:12:57	68.14
			AM Peak (7 – 8 am)	00:16:51	52.37
			AM Peak (8 – 9 am)	00:15:26	57.21
			PM Peak (4 – 5 pm)	00:21:15	41.54
			PM Peak (5 – 6 pm)	00:19:55	44.32
R310 Adam Tas Road SB	Annandale Road	12.770	Base Set	00:13:36	56.33
			AM Peak (7 – 8 am)	00:18:34	41.28
			AM Peak (8 – 9 am)	00:17:51	42.94
			PM Peak (4 – 5 pm)	00:21:35	35.50
			PM Peak (5 – 6 pm)	00:19:53	28.53
R310 (Helshoogte Road) NB	R45	14.016	Base Set	00:13:33	61.61
			AM Peak (7 – 8 am)	00:13:52	60.62
			AM Peak (8 – 9 am)	00:13:43	61.29
			PM Peak (4 – 5 pm)	00:13:56	60.37
			PM Peak (5 – 6 pm)	00:13:41	61.48

Furthermore, Table 6-6 indicates the base set, AM and PM peak travel times and speed for the garage storage location just north of the Molteno Road / R44 intersection to the end of the R44. The travel times from the Molten Road – R44 intersection to the other arterials are determined from subtracting the distance from the Unit Station to the garage storage location since these routes passes the garage.

Table 6-6: Summary of results for base set, morning and afternoon peaks from Molteno – R44 start point

Route followed	Route end intersection	Covered road length (kilometre)	Time set (hour)	Average travel time (HH:MM:SS)	Average speed, harmonised (km/h)
R44 NB	R101 (Old Paarl Road)	15.868	Base Set	00:12:46	74.53
			AM Peak (7 – 8 am)	00:15:41	60.69
			AM Peak (8 – 9 am)	00:15:22	61.96
			PM Peak (4 – 5 pm)	00:18:15	52.19
			PM Peak (5 – 6 pm)	00:19:38	48.51

6.2.3a) Speed analysis

Figures 6-2 to 6-4 indicates the routes from the Unit Station to the end points of the arterials and the harmonic average speeds on these routes for the base set as well as the 7 – 8 AM and 4 – 5 PM peaks. These peaks have consistently longer travel times. The key for the speeds is indicated in Figure 6-2.

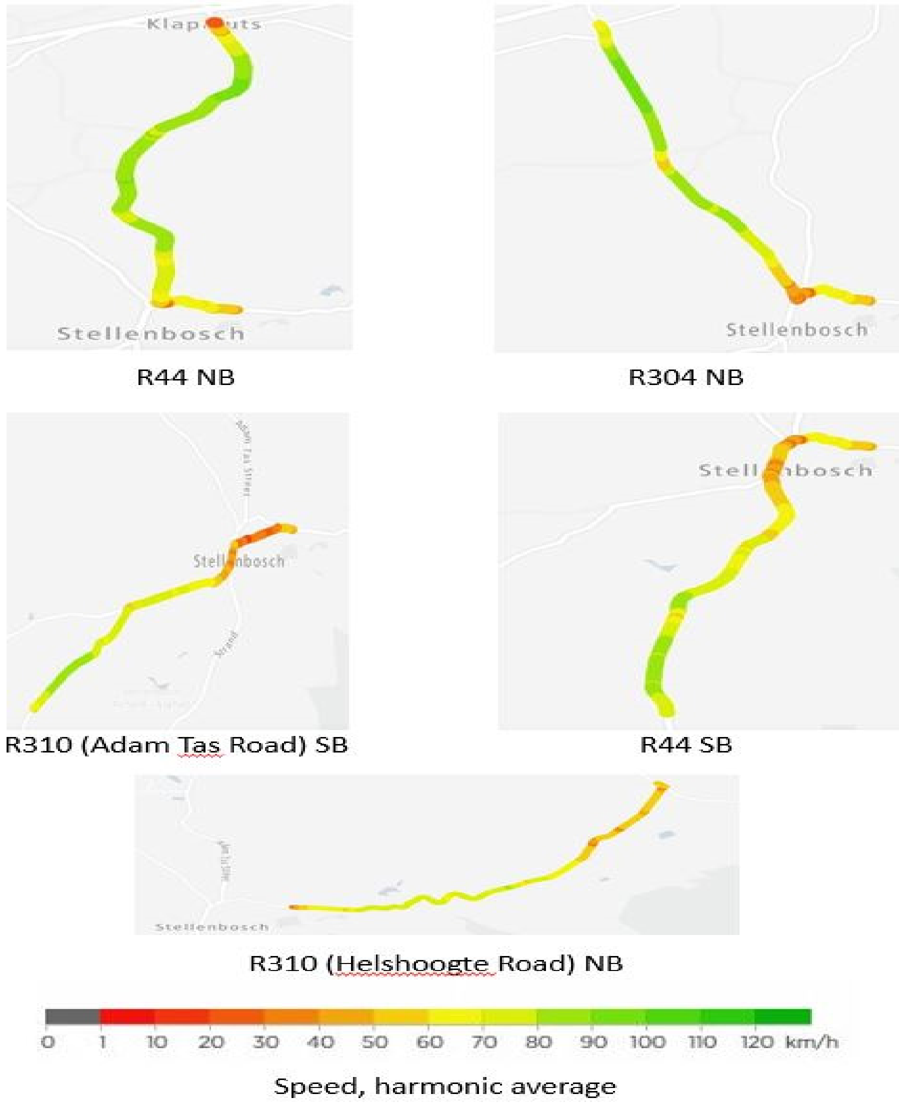

Figure 6-2: Base set speed

Figure 6-3: 07h00 - 08h00 AM peak

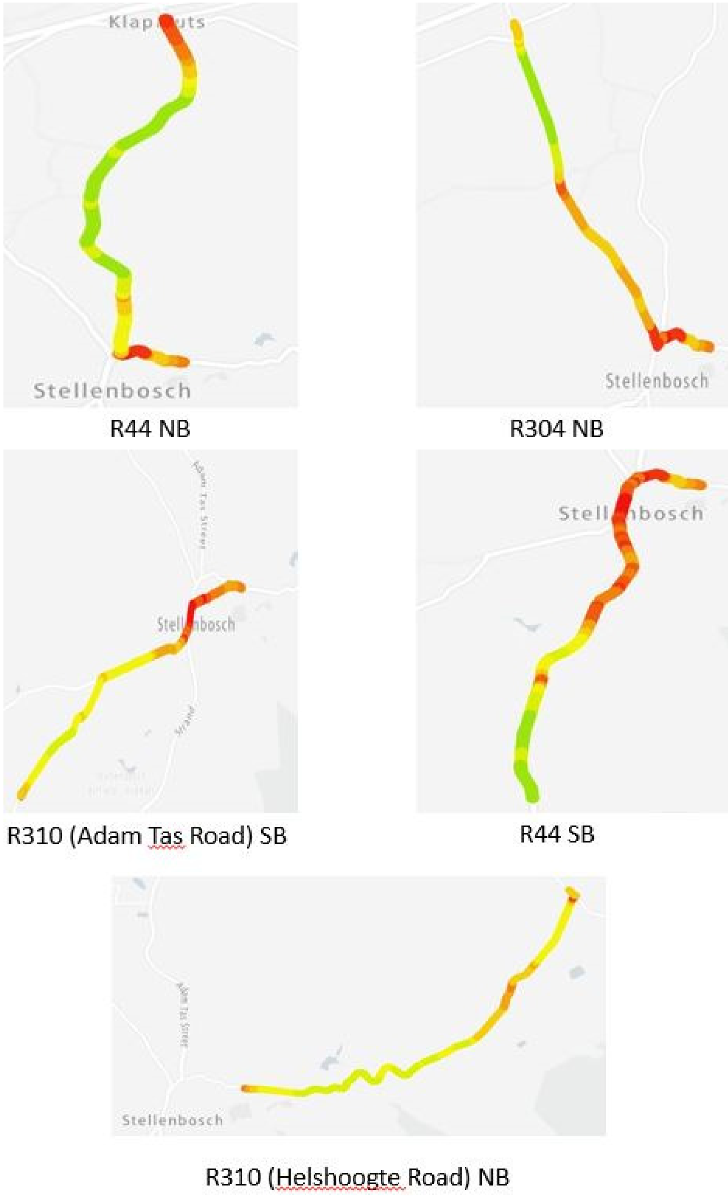

Figure 6-4: 16h00 - 17h00 PM peak

Referring to Tables 6-5 and 6-6 as well as Figures 6-2 to 6-4:

- Harmonic mean speed is used as it provides a better understanding of the speed data since it equalises the weights of each data point, allowing for a smoother image to assess.
- For all three time periods (base, AM and PM peaks) the slowest speeds are experienced in the centre of Stellenbosch.
- Although the Molteno Road garage space is located closer to Adam Tas Road than the Cluver / Helshoogte Unit Station, travelling from the exit of the garage space to enter the arterials causes a delay and does not provide much difference to the arrival time to end points.

- The R44 SB is the shortest route yet it takes the longest to complete, due to the high traffic between the Adam Tas Road / R304 and Adam Tas Road / R44 intersections.

Using the 85th percentile speed, the routes most affected by morning and afternoon traffic can be determined when these times periods are compared to the base set. The 85th percentile speed is the speed at which 85% of traffic travels at or below. This is used in road design when setting the speed limit on a road. Table 6-7 indicates the 85th percentile speed averages on the routes for the base set and worst AM and PM hour periods travelling from the Unit Station.

Table 6-7: 85th Percentile speeds

Route	Base set (km/h)	7 – 8 AM peak (km/h)	4 – 5 PM peak (km/h)
Adam Tas Road SB	76.33	64.46	58.71
R44 NB	95.56	84.9	80.92
R44 SB	83.46	66.64	63.25
Helshoogte Road	87.67	76.57	69.19
R310 NB	87.18	75.89	73.91

Analysing Table 6-7, the drop in speed between the base set and the peaks is evident. The R44 SB experiences the highest drop in speed and, when analysing Figures 6-2 to 6-4, this occurs on Adam Tas Road between the Adam Tas Road / R44 and Adam Tas Road / R304 intersections. This portion of road also experiences the highest traffic density and lowest speeds in the entire study area for the base set, AM and PM peaks. The 85th percentile speed analysis is inversely proportional to the travel time analysis since slower speed leads to longer travel times.

When assessing the FCD for the R44 SB, the morning peak period saw the 85th percentile exceeded the speed limit 45% of the time, whereas in the afternoon it only exceeded the speed limit 17% of the time. This show that traffic flow outbound in the afternoon is high yet the speed limit is exceeded. This could indicate an inadequate speed limit on the R44 SB.

6.2.3b) Travel time analysis for IMS Unit Station location

While analysing the travel time, only the one hour peak AM and PM periods are assessed since these would be the worst case scenarios. Since the incident response is being assessed, the peak AM and PM hour periods are chosen based on the peaks of the routes as a collective. With the base period being from 23h00 to 05h00, the AM peak period, based on the travel times in Table 6-5, is 07h00 to 08h00 since all the travel time is highest on all routes for this period. The PM peak for all the routes is 16h00 to 17h00, even though the R44 NB experiences its PM peak from 17h00 to 18h00. The PM peak is chosen as is so that the whole study area can be assessed during the same AM and PM peaks. The same reasoning applies for Helshoogte Road where the peak period is different (Helshoogte AM peak is 10h00 to 11h00 and its PM peak is 14h00 to 15h00).

The distance that emergency response vehicles travel in 5, 10 and 15 minutes from the Unit Station at the Cluver Road intersection with Helshoogte Road to the different arterials in the study area were assessed using FCD provided by TomTom®. Table 6-8 shows the distances along each route an emergency vehicle travels (distance measured using Google Maps) from the Unit Station on the R44 Northbound. The same procedure was followed for the other routes (the routes are indicated previously in Figure 6-2).

Table 6-8: 5, 10 and 15 Minute travel times from Unit Station on Cluver Road to the R44 Northbound (NB)

Cluver Road Unit Station - R44 NB		
Base set		
Distance along route (m)	**Cumulative TT (s)**	**Travel time (min)**
2708.62	175.61	2.93
3193.71	199.5	3.33
5242.94	298.6	4.98
12024.99	584.8	9.75
16906.35	810.88	13.51
full route complete in under 15 minutes for base set		
7 - 8 am PEAK		
3193.71	300.3	5.01
8722.03	570.41	9.51
16020.22	883.93	14.73
16906.35	972.95	16.22
4 - 5 pm PEAK		
1938.78	274.8	4.58
6897.82	578.44	9.64
13892.5	881.22	14.69
16906.35	1188.69	19.81

From Table 6-8:

- The distance the probe vehicle travels along the route was measured from the Unit Station at the Cluver Road / Helshoogte Road intersection, which was the start point. All routes followed directly on the arterials, except the route from the Unit Station to the R310 (Adam Tas Road) southbound, which detoured through Hammanshand Road and Molteno Road to Adam Tas Road. This was because, for the Cluver Road – R310 southbound route analysis, the detour provided a more direct route than travelling on Helshoogte Road and then southbound on the R310.
- Travel times are provided cumulatively in the FCD and is directly related to the distance along the route.

- The travel times highlighted in orange were the cut-off times for the maximum distance a vehicle could travel from the Unit Station down the arterial in question. Since the FCD provides travel times based on segments being made every few metres, the travel time closest to 5, 10 and 15 minutes were chosen (the next recorded travel time after 4.98 minutes in the base set, for example, was 5.10 minutes, which is more than 5 minutes).
- The bold text in the 'distance along route' column is the full length of the route from the Unit Station to the end of the arterial as indicated in the study area description. If the full route was completed before 15 minutes, this bold text value coincides with the highlighted yellow travel time.

Since the response time to the end of certain arterials were longer than 15 minutes, the garage space at the Molteno Road / R310 (Adam Tas Road) intersection was used as a secondary deployment site that also provides response to incidents occurring at the following locations:

- R304 NB
- R44 NB and SB
- R310 (Adam Tas Road) SB

Both locations, the Unit Station and the garage space, are used and IMS units are split between these two deployment sites. This is to ensure that response to any incident scene in the study area is carried out efficiently and as fast as possible. Both locations are also used because although one deployment site may be closer to a specific arterial, the time it takes for response units to enter any given arterial differs based on traffic throughout the study area.

In addition to the arterial route analyses, an area analysis was done that assessed the travel times for the urban roads in the study area. This was used to assess the travel times for the base, morning and afternoon peak periods. From both the route and area analyses, a map representing the areas to which a response unit leaving from either the Unit Station or the garage space can respond to, was created. The base time set, morning peak and afternoon peak each has their own map. These are indicated in Figures 6-5 to 6-7.

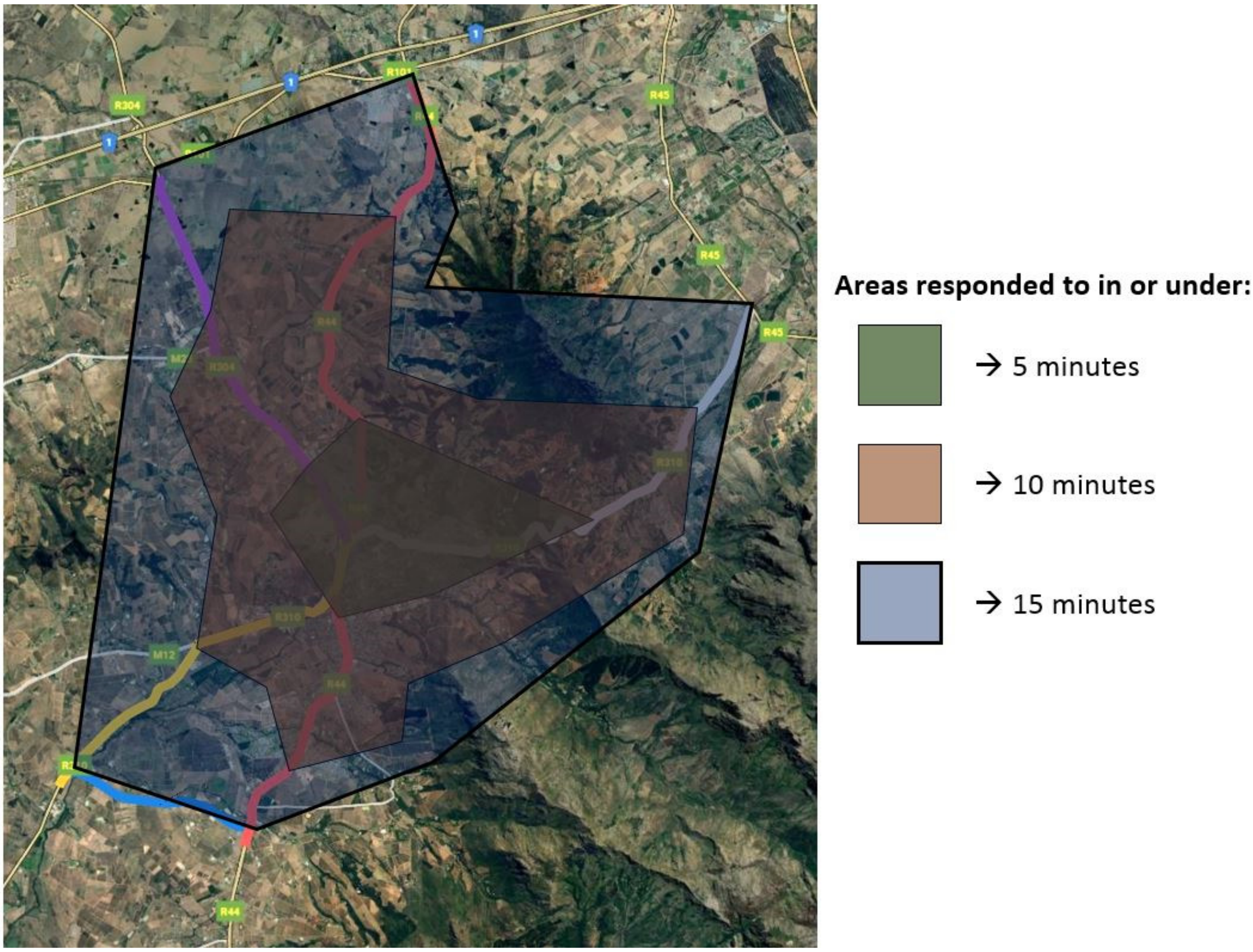

Figure 6-5: Travel time response map for base set

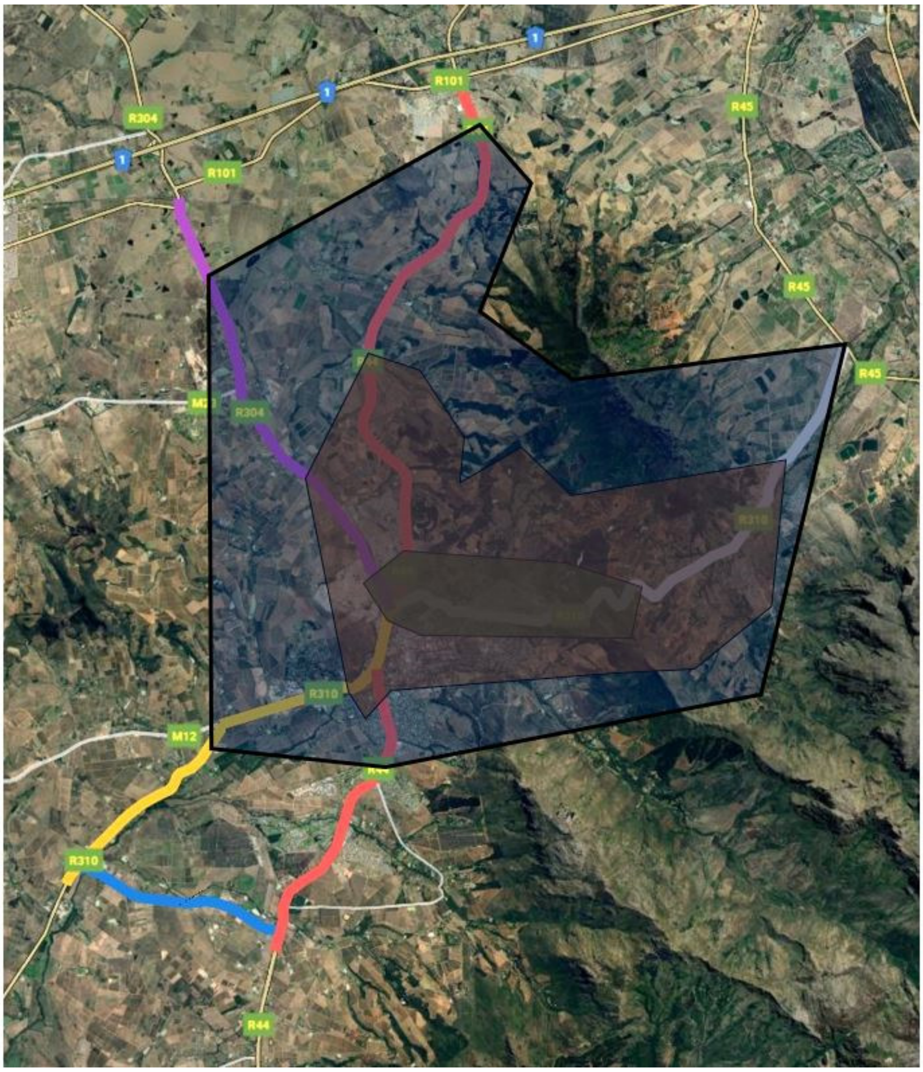

Figure 6-6: Travel time response map for AM peak

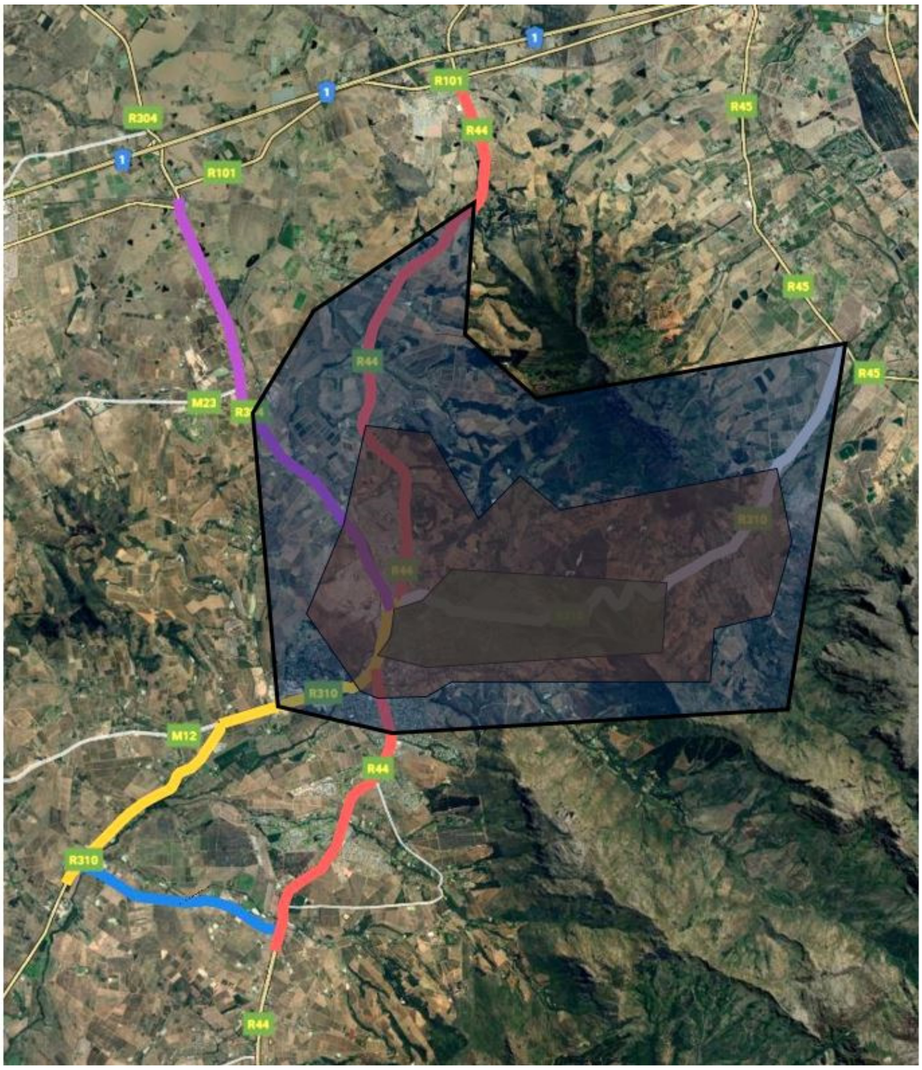

Figure 6-7: Travel time response map for PM peak

The key is indicated in Figure 6-5 and Figures 6-5 to 6-7 shows the areas that can be responded to in 5, 10 and 15 minutes. Based off these figures:

- For the base period, any location within the study area can be responded to in under 15 minutes. This is due to the low traffic at these hours (23h00 to 05h00).
- Overall, the PM peak experiences the worst traffic and response times to the end points of all the arterials, except the R310 NB, are the highest. Analysing both the AM and PM peak travel time maps with the FCD indicates a large portion of time is spent between the R310 (Adam Tas Road) – R44 and R310 (Adam Tas Road) / R304 intersections. This is due to the bottlenecks formed at the Adam Tas Road / Merriman Avenue and Adam Tas Road / R310 intersections when university students and staff, school students and other workers are all exiting Stellenbosch.

- In total, 52.40 km of arterial roadway is covered in the morning peak hour and 45.60 km in the afternoon peak hour. In contrast, 14.1 km and 24.3 km of roadway are not covered in at least 15 minutes during the morning and afternoon peak hours respectively. Table 6-9 indicates the difference in length from the point a response vehicle arrives at in 15 minutes to the end of the arterial in the morning and afternoon peak hours. Table 6-10 indicates the time it takes to travel from the furthest point where a response vehicle can respond in 15 minutes to the route end, for the morning and afternoon peak hours.

Table 6-9: Length of route not covered in 15 minutes for AM and PM peaks

Route	AM peak at 15 minutes (km)	PM peak at 15 minutes (km)	Total route length (km)	AM difference (km)	PM difference (km)
R44 NB	16.02	13.89	16.90	0.88	3.01
R44 SB	4.88	3.89	11.51	6.63	7.62
R304 NB	12.49	8.19	14.71	2.22	6.52
R310 Adam Tas SB	8.43	5.60	12.77	4.34	7.17
R310 Helshoogte NB	14.016	14.016	14.016	0	0
Total				**14.1**	**24.3**

Table 6-10: Travel time from 15 minute point to route completion

Route	AM peak completion (min)	PM peak completion (min)
R44 NB	1.49	5.12
R44 SB	1.98	5.6
R304 NB	1.85	6.25
R310 Adam Tas SB	3.93	6.73
R310 Helshoogte NB	0	0

From Tables 6-9 and 6-10:

- There is not a direct correlation between the difference in kilometres in Table 6-9 and the time difference in Table 6-10 since traffic speed, speed limits and other factors such as weather conditions and driver behaviour affect traffic flow.
- Majority of the delay is created in the central parts of Stellenbosch where the traffic density is at its highest due to an accumulation of motorists in the morning and the large outflow of

motorists in the afternoon. This, accompanied with bottlenecks formed throughout Merriman Avenue, Victoria Street and Banghoek Road, causes the delay.

- The route which draws the most attention is the R310 Southbound, which an incident could possibly be responded to in a maximum of 18.93 minutes during the morning peak and 21.73 minutes in the afternoon peak, if this incidents occurs at the end of the route.

6.2.3c) Speed and travel time analyses discussion

Although the location of the Unit Station does not allow for full coverage of the entire study area during the morning and afternoon peaks, the location is suitable since it is central to the areas which experience high traffic volumes. This is good since there will be a higher risk of an incident occurring at the higher traffic volume areas.

Another reason why the location is suitable is due to the fact that when an incident occurs, emergency response gets priority on roadways heading to the incident scene. This causes the travel time to an incident to be lower than as observed in the FCD because the FCD provides average travel time for all vehicles. Along with signal prioritisation for emergency vehicles, response units will arrive at incident scenes sooner than indicated by the FCD and the signal prioritisation reduces the chance of any incidents occurring with the response units. The time difference between a response unit arriving at the scene and the time indicated in the FCD is unknown since this is affected by various factors related to the traffic conditions on the road, weather conditions and driver behaviour. The maximum amount of time it would take a response unit deployed from the Unit Station or the garage space to arrive at a possible incident the furthest point away is 6.73 additional minutes to the 15 minute period (total of 21.73 minutes). This is acceptable since emergency vehicles generally travel faster than the speed limit on the road, which also reduces its arrival time to incidents.

In addition to this, the applicability of the Unit Station's location can be determined when analysing the response time for emergency vehicles from the Unit Station to high accident zone areas. Historic accident information for Stellenbosch for the years 2014 – 2016 was provided by Professor Marion Sinclair from Stellenbosch University and assessed. In total, 7094 road-related incidents occurred over the three year period, ranging from non-injury accidents to fatal accidents. The four roads with the highest number of accidents (or in the vicinity of the road) are: Adam Tas Road (to Vredenburg intersection SB, 1.5 km north of Helshoogte Road / Adam Tas Road intersection NB), Bird Street, Merriman Avenue and the R44. An acceptable response time to the furthest point on these roads from the Unit Station would mean that the location of the Unit Station is appropriate. Table 6-11 indicates the response time to the furthest point on these roads from the Unit Station for the base, morning-and-afternoon peak periods. The number of accidents and the percentage of total accidents on these roads are also provided in Table 6-11.

Table 6-11: Response time to accident hotspots on four different roads in Stellenbosch

Road	Number of accidents	% of total (7094) accidents	Base period response time (minutes)	AM Peak response time (minutes)	PM Peak response time (minutes)
Adam Tas Road SB	307	4.32%	9	14.9	17.2
Adam Tas Road NB	79	1.11%	3.6	6.2	9.3
Bird Street	802	11.3%	3.2	8	11.4
Merriman Avenue	428	6.03%	2.5	9.7	7.6
R44	1294	18.24%	11.5	17	20.6
Total	**2910**	**41%**			

From Table 6-11, it is evident that the only roads that exceed the 15 minute response time limit is Adam Tas Road Southbound for the PM peak and the R44 for the AM and PM peaks. The Unit Station's location is therefore appropriate since, even though exceeding 15 minutes, other factors mentioned previously such as response vehicles traveling at higher speeds, would lower this response time, bringing the overall response time to all these roads closer to 15 minutes.

6.3 FCD vehicle detection vs Vehicle Detection Sensors (VDSs)

A big difference in TM 2 from TM 1 is the replacement of majority of the VDSs and loop sensors with the use of FCD. In TM 1, the cost of VDSs for arterial and urban coverage as well as the cost of loop sensors amount to R4,005,804.00 whereas in TM 2 the reduced number of VDSs, coupled with the use of FCD, amounts to R1,735,070.00. This individual area of analysis provides a cost saving of R2,270,734.00. When opting to use FCD for vehicle detection and traffic data collection in TM 2, the biggest issue that arises is the accuracy that FCD provides compared to traditional road sensors. To assess this, literature is consulted. It was initially planned to test the FCD vehicle detection in the TMC in Cape Town but access restrictions due to the COVID-19 pandemic halted this effort.

Figure 6-8 provides the comparison in average speed accuracy collected by Tag-based Tolls and by TomTom respectively on the US 290 Houston Highway located in Texas (Gwara, 2017). The data was compared for a period of 14 hours, from 05h00 to 19h00.

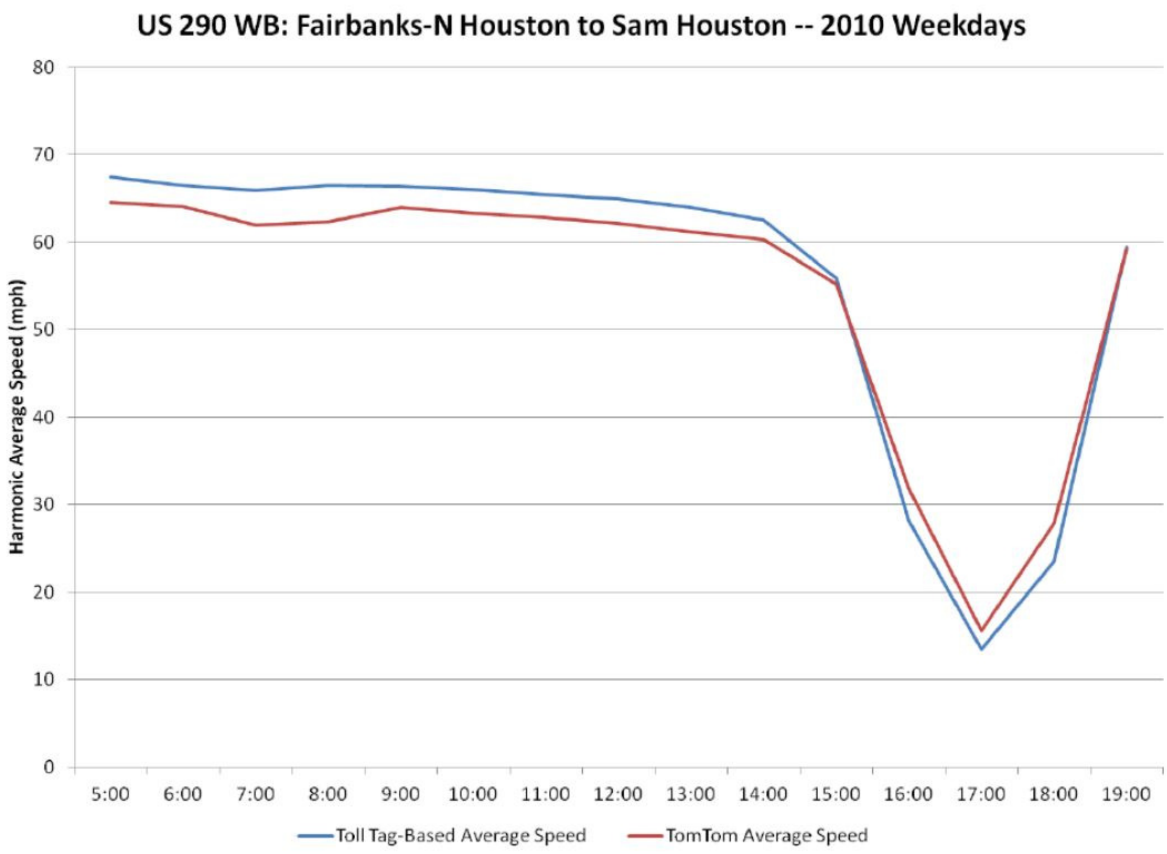

Figure 6-8: FCD and road sensor data collection comparison for US 290 (Gwara, 2017)

Figure 6-9 assesses the accuracy of average speed supplied by TomTom on a portion of the N1 Highway in Midrand, Johannesburg, compared to speed data obtained from the Open Road Tolling (ORT) System.

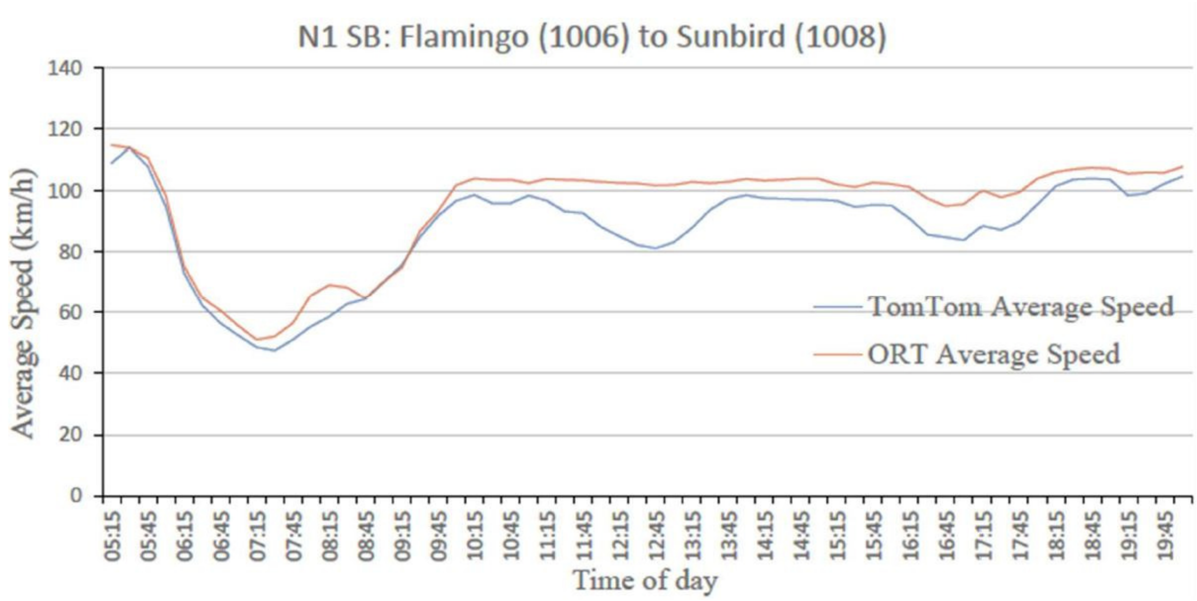

Figure 6-9: FCD and road sensor data comparison for a portion of the N1 Highway in Johannesburg (Gwara, 2017)

From Figures 6-8 and 6-9, although the proportion of vehicle probes are only about 5%, there is only a slight variation in the speed data between the two sources. The average absolute speed error (AASE) was used in both studies to assess the accuracy of FCD speed estimates. The AASE for 15-minute speed collection intervals for the combination of freeway segments assessed was 6.4 km/h. For hourly periods, the AASE was 6.5 km/h. This means that the average speed collected by the two different methods differed by a magnitude in the region of 6 km/h (Gwara, 2017). In terms of accuracy for the freeway segments assessed, the consistency of TomTom's speed profiles are relatively high as compared to the speeds obtained by ORT.

This can be used to motivate the appropriateness of using FCD for vehicle detection. However, the issues arises that vehicle detection needs to occur in real-time and assessing historical speeds cannot achieve this function but only motivate it. Due to this, INRIX data representing the delivery of real-time data was assessed in a study by the Bavarian Transportation Department (INRIX, 2015). The results of this study are indicated in Figure 6-10. Figure 6-10 assesses the percentage of FCD transmitted by INRIX for different roads of Class A (single or dual carriage highways with high speed limits) and Class B (lower traffic density distributor roads).

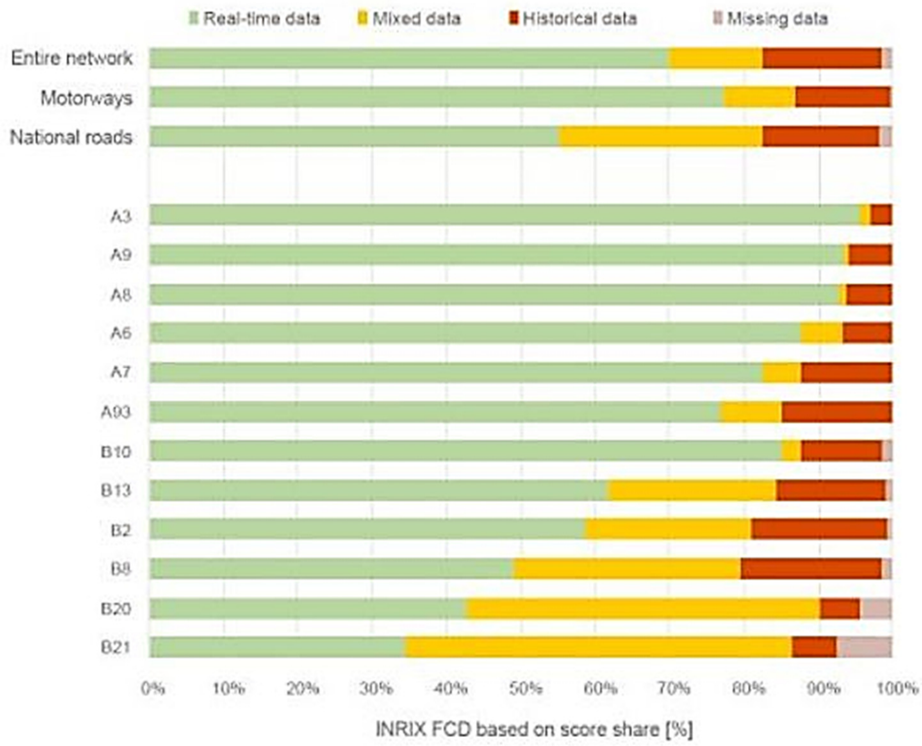

Figure 6-10: Percentage of INRIX FCD transmitted for each road class (INRIX, 2015)

From Figure 6-10, it was found that INRIX had the ability to deliver real-time data 70% of the time, which indicates high FCD quality. Furthermore, real-time FCD delivered on motorways occurred at 77% and 55% of time on national roads (INRIX, 2015). TraffiCon, a Bavarian-based ITS consultant, found that traffic data obtained from FCD corresponded to road sensors 90% of the time (INRIX, 2015). The assessment made by the Bavarian Transportation Department concludes that FCD is consistent and accurate enough to provide efficient traffic management.

A concern with using FCD for vehicle detection arises during off-peak hours when there may not be a high number of vehicle probes on the road network due to low traffic volume. Although this issue is present, the use of FCD is still preferred for estimation of traffic flow patterns and speed profiles for the road network. Although FCD traffic information may not be as consistent during off-peak hours, it is still preferred as the accuracy for the peak period is high and the need for vehicles to be detected during off-peak hours does not affect the overall management of traffic, since vital locations of the arterial network are under surveillance with the use of CCTV cameras in TM 2. Furthermore, the benefits associated with a reduced number of VDSs coupled with FCD for Stellenbosch are:

- FCD is non-intrusive, meaning no physical hardware needs to be installed on the road network. This reduces the cost of traffic management since hardware does not need to be installed and there is no maintenance cost that needs to be paid.
- Although only 5% of vehicles are probes on the road network, this provides data with a relatively high accuracy as compared to data provided by road sensors. This would imply that, as vehicles develop and become more technologically-advanced, the number of vehicle probes should (theoretically) increase, causing future traffic data to be more accurate.
- FCD provides traffic data for the entire study area including all minor urban and rural roads. VDSs only provide data for the portion of the roadway they are installed on.
- FCD does not need any processing once received and can be used as is, whereas data obtained from road and loop sensors needs to be processed using a computer program.

6.4 Traffic management capability of UAV system

In addition to the use of FCD in TM 2, Unmanned Aerial Vehicles (UAVs) are used to monitor traffic congestion, confirm incidents, and assist in traffic management. The majority of the CCTV cameras present in TM 1 are not included in TM 2 and UAVs aim to regain some of the functionality lost as a result of this. The implementation of UAVs caused TM 2 to be substantially cheaper than TM 1. The cost of CCTV cameras in TM 1 amounted to R12,222,649.30. The cost of the reduced number of CCTV cameras in TM 2 is R2,404,455.60 and the cost of the UAVs and associated components is R797,386.00. The amount of money saved when implementing UAVs and reducing the number of CCTV cameras is R9,020,807.00. As indicated in Section 6.1, the percentage of arterial roadway covered by CCTV cameras in TM 1 is 32%, and 8.4% in TM 2.

Since many variables have to be considered when comparing traffic management of UAVs and CCTV cameras, such as the time an incident occurs, non-linearity when comparing the FoV of a CCTV camera (horizontal) and a UAV camera (vertical), varying hours that UAVs could be operated, the number of UAVs and CCTVs, and the flight time of UAVs, the capability of the UAV traffic management system is best assessed in a descriptive manner instead of with any calculations. This is done by assessing the benefits of both CCTV cameras and UAVs and what impact each of these components has on traffic management.

6.4.1 Benefits of UAV traffic management

Along with being the cheaper option, other benefits associated with implementing UAVs in traffic management for Stellenbosch are:

- UAVs are not fixed to one specific location as CCTV cameras are and can be controlled remotely. This allows for better inspection of possible causes of congestion and incident scenes and provides information to traffic management operators without the need to leave the base of operations. This is for a radius of up to 7 km from the deployment station, in line with the maximum distance the DJI Inspire 2 UAV can fly from the remote.
- Stellenbosch is a town where non-motorised transport (NMT) is prevalent and used by many people. An upside of using UAVs in such a town is the added surveillance it offers to areas inaccessible to cars or areas where an overloaded CCTV camera system would not be economically viable.
- UAVs provide a larger FoV with its aerial imagery and this can be used to determine where bottlenecks and dense traffic volumes will occur relative to an incident scene. This information can be used by VMS operators to notify motorists on the relevant roadways about the incident and to inspect delays.

- The roaming coverage provided by UAVs causes it to be a good replacement of many Urban CCTV cameras if implemented in a manner that considers the battery life and flight distance from the remote.
- With no physical hardware needing to be installed, no annual maintenance is needed which decreases the cost of implementing TM 2. Furthermore, in UAVs need to be maintained or replaced, this can be done in a considerably shorter amount of time as compared to maintaining on-road cameras or camera infrastructure.
- As technology develops, cities and towns will become more technologically oriented in the near future. The range of applications of UAVs is growing as it is becoming more prevalent in many industries and being up to speed with the paradigm shift will allow management of traffic to be a less tedious activity (having operators sit and watch a monitor for 8 hours a day) and rather a more effective one by using UAVs efficiently.
- With the development of technology, tools such as video recognition, pattern analysis and Artificial Intelligence (AI) can be used with UAV footage to programme a UAV to autonomously identify and report the occurrence of an incident, which reduces the delay in incident response.
- As many countries are adopting the use of UAVs in various fields, regulations for the base technology will ease, which will cause UAVs to be easier to implement in the near future.
- In this study, only traffic during the morning and afternoon two-hour peaks were monitored using UAVs. Since UAVs decreased the cost of TM 2 substantially, future studies could assess the impact of a full UAV-based traffic management model with no CCTV cameras and base stations located throughout the study area.
- UAVs offer benefits to incident management as well, improving how efficient an incident is responded to and cleared.

6.4.2 Limitations associated with UAV traffic management

Since UAVs are not used much for traffic management in South Africa, certain limitations arise, such as:

- A lack of presence in government policies may cause the implementation of UAVs in traffic management to be delayed. In addition to this, although flight regulations are being eased in other countries, South African transport authorities may be reluctant to allow UAVs special flight permissions such as flying close to buildings and airports or flying over roadways.
- When using UAVs, two issues that arise are the limited flight time due to the battery life of the UAV, and the operational limit relating to the UAVs' distance from the control. For

Stellenbosch, the UAVs can only travel a radius of 7 km from the deployment station and, in practice, will be flown up to 4 km from the station to avoid any unexpected error relating to the signal of the UAV from the control. These limits cause the operational area of the UAVs to be a small radius in the centre of Stellenbosch and roadways out of this 4 km radius are not managed with UAVs. The limited number of CCTV cameras and FCD, however, makes up for this loss of traffic management capability.

- Due to the limited battery life, 24-hour traffic monitoring is not possible with the system used in this study. Thus, only the morning and afternoon peak periods were assessed in this study. More UAVs and UAV pilots would be required to monitor traffic if a larger UAV network is to be used, which could become expensive considering the cost of UAV licenses.

6.5 Delay in incident response

Following from the travel time assessment in Section 6.2 that tested incident response time for different peak periods, this section aims to provide the time difference between TM 1 and TM 2's incident detection, response and clearance. An analysis of the benefits and limitations relating to incident response between the two TMs is also provided.

There is no variation in hardware cost for the Incident Management System between TM 1 and TM 2. The cost of hardware for both TMs is R2,748,019.30. The only additional cost that occurs between the two TMs is that of the single UAV used for the UAV Incident Unit (UAVIU), which is R152,662.00.

6.5.1 Incident management capability comparison

To compare the incident management and response capability of the two TMs, TM 2 is compared to TM 1 (TM 1 is therefore used as a basis for comparison). The travel times for TM 1 have been provided previously in Section 6.2. The difference in incident response for the two TMs are as follows:

- TM 1: Incident is identified by camera operators, social media notification or people calling emergency response. The relevant IMS unit is then dispatched based on information provided from the aforementioned sources.
- TM 2: Incident is identified by the same sources as for TM 1, or by UAVs or FCD. A UAVIU is sent to the scene to investigate it when uncertainty arises around which response unit must be sent out. The UAVIU operator then advises the IMS on which response unit to send to the incident scene. There is a potential for high variation here: If initial incident identification sources picks up a severe incident before the UAVIU responds, the relevant response team can accompany the UAVIU to the scene (if the incident scene is further than 7 km from the Deployment Station), either in the same or with a different vehicle, depending on the characteristics of the incident.

It is evident that the response time for TM 2 is therefore longer than for TM 1. The additional time it takes for the IMS of TM 2 to clear an incident depends on the location where an incident occurs. Recall that the UAV used in this study (DJI Inspire 2) has a maximum controllable distance of 7 km from the remote. The additional incident response time for TM 2 therefore needs to be determined for two scenarios: for incident occurring within a 7 km range from the Deployment Station, and for incidents occurring outside of this range. Figure 6-11 indicates this range for the study area.

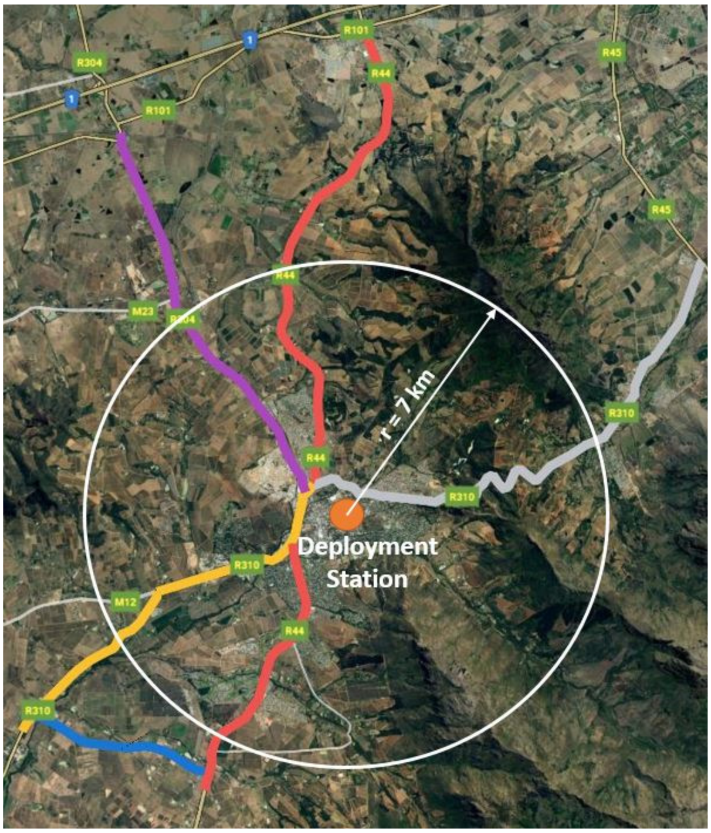

Figure 6-11: 7 Km radius from Deployment Station (↑N)

6.5.2 Incidents occurring less than 7 km from Deployment Station

Since a UAV can fly in a straight line to its location, the maximum amount of additional time it would take to respond to a scene within a 7 km range of the Deployment Station would be when an incident occurs 7 km from the Deployment Station (the maximum distance away). Recall from Section 5.3, if the UAV is flown at its maximum speed of 94 km/h, it arrives at a scene 7 km from the Deployment Station after $s = \frac{d}{t}; t = \frac{d}{s} = \frac{7}{94} = 4.5\ minutes$. The delay in detecting an incident from FCD is approximately 2 minutes. Once the incident is detected, the UAV is deployed immediately. The time from an incident occurring to identification and confirmation by footage from the UAV, therefore introduces an additional 6.5 minutes to the incident response for incidents within a 7 km range in addition to the travel and deployment of the UAVIU.

Table 6-12 indicates the time it takes for response vehicles to reach the positions on the roadways that are a 7 km straight distance from the Deployment Station. This was determined using FCD. Only the worst case scenario is assessed because if the system is adequate for the worst case, less severe cases are also accounted for. The slowest time period for Stellenbosch is the PM peak and this period is used as the worst case scenario. The actual roadway kilometre distances are also provided in Table 6-12. To simplify the analysis, only the arterials were assessed in this manner. The on-road distances are based on the routes indicated in the FCD analysis in Section 6.2, and start at the Deployment Station. The travel time with the additional 6.5 minutes is also indicated in Table 6-12.

Table 6-12: Response vehicle travel time for UAV flight distance of 7 km

Road	On-road distance (km)	Response vehicle base travel time without UAVIU inspection (minutes)	Response vehicle travel time after UAVIU inspection (minutes)
R44 NB	7.94	10.65	10.65 + 6.5 = 17.15
R44 SB	10.57	17.56	17.56 + 6.5 = 24.06
R310 (Helshoogte Road) NB	8.57	7.17	13.67
R310 (Adam Tas Road) SB	8.38	17.31	23.81
R304 NB	8.73	15.89	22.39

6.5.3 Incidents occurring further than 7 km from Deployment Station

For incidents occurring further than 7 km from the Deployment Station, the UAVIU (UAV + UAV operator) is deployed to the incident scene. The UAVIU arrives at the scene after the same travel times indicated in Table 6-12 before incident assessment occurs. Video footage is then assessed for roughly 2 minutes and an analysis is made and the relevant response units (IRU, LTU or HTU) are sent to the scene, arriving at the scene after the same travel time indicated in Table 6-12. These response times are presented in Table 6-13. To simplify the analysis, an assessment for an incident occurring immediately out of 7 km range (at 7.001 km from the Deployment Station) is provided. This allows the same response times to be used as in Table 39.

Table 6-13: Response times for incidents occurring > 7 km from Deployment Station

Road	On-road distance (km)	Time after which UAVIU incident inspection is complete (minutes)	Time after which relevant response units arrive at incident scene (minutes)
R44 NB	7.94	17.15	17.15 + 10.65 = 27.80
R44 SB	10.57	24.06	24.06 + 17.56 = 41.62
R310 (Helshoogte Road) NB	8.57	13.67	20.84
R310 (Adam Tas Road) SB	8.38	23.81	41.12
R304 NB	8.73	22.39	38.28

From Tables 6-12 and 6-13, it is evident that using the UAVIU causes an incident to be responded to after a longer period of time. There are, however, considerations that need to be taken which affect the times indicated in Tables 6-12 and 6-13. These considerations are:

- This analysis has only been conducted for the PM peak period for Stellenbosch. Different times of the day will yield shorter travel times.
- Private road-side assistance and tow-truck companies operate in Stellenbosch, who may respond to an incident sooner. This is communicated with traffic management in TM 2 to ensure no additional response units are sent out.
- The UAVIU is used in cases of uncertainty when determining which response unit should be sent out.

Finally, the biggest consideration arises when using the travel time provided by the FCD which is the average for all vehicles on the road network. Response units travel faster than the average traffic speed and are allowed to waiver speed limits and traffic managing practices of signalised intersections.. Based off this, an additional analysis is done. From the point when a response unit exits the Deployment Station until it reaches the incident scene, the speed of the response unit varies. From consulting various discussion forums relating to emergency response, a good assumption is that an emergency vehicle drives at a constant speed of 45 miles/hour (≈ 72 km/h, use 70 km/h) over the length of its journey. This holds for cars but for LTUs and HTUs, the travel time to an incident is slightly longer than indicated in the FCD because it is unsafe for a large vehicle to contravene speed control measures. LTU and HTU travel times are also longer due to slower speeds. From this assumption, a more realistic analysis can be conducted using the Equation $s = \frac{d}{t}$. A better basis for comparison between TM 1 and TM 2 is therefore created by considering an incident that only requires and IRU. Table 6-14 provides this analysis for an IRU travelling at 70 km/h, for incidents occurring just outside of the UAV's 7 km flight range from the Deployment Station. Table 6-14 also takes into account the time it takes for a CCTV operator to detect an incident. This reaction time is chosen as 3 minutes based on the research that Claire Birungi conducted at the TMC in Cape Town (Birungi, 2019). Due to the COVID-19 pandemic and associated lockdown regulations, an assessment of how quickly an incident is detected using FCD, compared to when FCD is not used, was not conducted. For simplicity, the reaction time for TM 2 is therefore chosen as 3 minutes.

Table 6-14: Response time to an incident > 7 km from the Deployment Station during the PM peak for TM 1 and TM 2

Road	On-road distance to incident (km)	TM 1: Travel time (minutes) ($s = \frac{d}{t}, \therefore t = \frac{d}{s} + 3$)	TM 2: Travel time (minutes) (= TM 1 Travel time * 2 + 2 +3 minutes)
R44 NB	7.94	6.81 + 3 = 9.81	18.62
R44 SB	10.57	9.06 + 3 = 12.06	23.12
R310 (Helshoogte Road) NB	8.57	10.35	19.69
R310 (Adam Tas Road) SB	8.38	10.18	19.36
R304 NB	8.73	10.48	19.96

From Table 6-14:

- The travel time for TM 2 is calculated using the same method as in Table 6-13. For TM 1, the travel time for an IRU to arrive at the incident scene is calculated directly from the speed-distance-time equation. For TM 2, the travel time is doubled since the UAVIU needs to arrive at the scene and assess the incident, and the relevant response unit is sent afterwards. The additional 2 minutes is the time for the UAV to be used to inspect the incident site.
- The UAVIU and IRU use the same type of vehicle.
- For TM 2, the response time is almost double that of TM 1.

6.5.4 Benefits of TM 2's incident response over TM 1

There are many benefits that TM 2's incident response system provides even though a delay of almost double the response time as in TM 1 occurs. These benefits allow TM 2 to be more adaptable, and are:

- Table 6-14 only assesses the condition that an IRU is required to respond to an incident. Other types of incidents can occur, which may require an LTU or HTU to clear the roadway for traffic to continue flowing. The benefit of TM 2 is that an UAVIU can be sent to an incident that is not in the view of the CCTV cameras and if information related to the incident is not sufficient enough to determine which response unit to send. As opposed to TM 1 which would send an IRU to any incident, the incident might not be serious enough to require any medical assistance (it could be a damage-only collision) and thereafter an LTU or HTU would be required to clear the roadway. This would take an excess amount of time and sending TM 2's UAVIU would provide this necessary information to the IMS, adding to incident arrival time but reducing on-site management and clearance, as well as the overall incident response time.

- UAVs provide a better understanding of an accident by obtaining aerial imagery which can be used to determine a quicker way to clear the roadway of an accident or an easier method of moving a vehicle that may be trapped in an unconventional location.
- Private medical response or independent roadside assistance might arrive at an incident scene before one of the IMS's response units and sending a UAVIU will notify the IMS of this. The UAVIU can then assist private medical or roadside units.
- Weather conditions such as heavy rainfall may hinder the capability of CCTV cameras' horizontal view and the vertical footage provided by a UAV is beneficial in this scenario.

6.6 Economic evaluation

For the analysis of the efficiency and cost-effectiveness of the two Test Models to be complete, an economic evaluation of each TM is required to assess economic viability. The economic evaluation creates a better understanding of the opportunity costs (benefits) that one TM has over the other by considering each TM's costs over a life cycle period of a specified number of years. The life cycle period provides the annual costs associated with the different components of each TM and this is useful in determining how much each component of a TM affects the project budget.

In practice, each additional alternative design is compared to a base-state model, called the do-nothing alternative. This allows a good basis of comparison in assessing the benefits and costs associated with each alternative considered. For this study, however, the do-nothing alternative is not used for comparison for the following reasons:

- The quantities of components used in TM 1 and TM 2 are unknown for the do-nothing alternative (number of CCTV cameras, ESSs, VDSs, and incident response vehicles).
- Determining the quantity of these components would require many extensive site investigations throughout the entire study area and this would be extremely long to conduct and quantity counts may not be accurate.
- To evaluate the economic viability of traffic management components and systems, the do-nothing alternative does not provide the same level of comparison as it would compared to generic projects that use economic evaluation, such as construction of a road, railway line or additional bus route.

There a different economic indicators that can be used to assess the viability of a project. For this study, the following four indicators are determined so that an in-depth economic analysis of the two TMs can be conducted:

1. **Present Worth of Costs (PWOC)**: The PWOC provides the present year value (Present Worth, or PW) of all the costs associated with a project, discounted to a value for year 0 (present year).
2. **Net Present Value (NPV)**: The NPV is the difference between the present value of cash inflows and the present value of cash outflows over a period of time.
3. **Benefit-Cost Analysis (BCA)**: The BCA provides the economic strengths and weaknesses of a project and is used to determine the best project choice based on the benefits and preserved savings.

4. **Internal Rate of Return (IRR)**: The IRR indicates the annual growth an investment is expected to generate and is calculated using the same concept as NPV. The NPV for the IRR, however, is set to zero.

The Equations used to determine these four indicators are:

$$PWOC = initial\ costs + PW(maintenance) \qquad \text{.......... Equation 1}$$

$$NPV = PW(maintenance) - initial\ costs \qquad \text{.......... Equation 2}$$

$$BCA_{TM\ x} = \frac{PW_{Benefits,TM\ x}}{initial\ costs_{TM\ x}}, where\ x = TM\ assessed \qquad \text{.......... Equation 3}$$

$$IRR: Determined\ using\ NPV = 0 \qquad \text{.......... Equation 4}$$

The economic analyses conducted in this study will assess a lifecycle period of **n = 20 years**. TM 1 and TM 2 are mutually exclusive alternatives, meaning that both Models serve the same purpose and, when one is implemented, the other cannot be implemented (Krygsman, 2020). it is important to note that these economic indicators are determined using the cost of hardware, equipment and components only and does not include the cost of employee salaries.

Furthermore, an appropriate discount rate needs to be used to discount future costs to year 0 values. Since the value of an investment changes over time due to the value of the Rand fluctuating over time, the discount rate helps determine if future cash flows from an investment will outweigh the initial funding cost. The discount rate depends on the class of the asset used and is determined using the Equation

$$Discount\ rate\ (i) = desired\ return\ rate + inflation\ rate + risk\ premium \qquad \text{.......... Equation 5}$$

Where:

- Desired return rate = the minimum rate of return that an investor determines for the amount of risk assumed (Chegg Study, 2020)
- Inflation rate = the rate at which the price of an investment, goods or service rises
- Risk premium = the expected return on investment of an asset in excess of a rate of return that is risk free (Investopedia, 2020)

Based off the information provided by Vertical Spaces (2020): for the asset class of cash, a return rate of 1% is used. Furthermore, the inflation rate for cash is 6% and the risk premium is 1%, bringing the discount rate on cash investments used for this study to **i = 8%** (Vertical Spaces Properties, 2020).

Finally, the amount at year n can be determined using the Equation

$$F = \frac{P}{(1+i)^n} \qquad \text{.......... Equation 6}$$

Where:

- F = the future value of the cost considered
- P = the present value of the cost considered
- i = the discount rate
- n = the year discounted from

The amount used for maintenance is the same amount indicated in Chapters 4 and 5 for TMs 1 and 2 respectively, namely 15% of the initial cost. Maintenance occurs every two years. If there is a cash overflow resulting from maintenance, then this excess funds can be used in other areas of management for traffic systems, hardware and software. Furthermore, it is assumed that installation of all hardware and components takes one year.

6.6.1 Discounting of initial and maintenance costs

The cost of hardware, equipment and components as well as maintenance costs, determined in Chapters 4 and 5 for TM 1 and TM 2 respectively, are indicated in Table 6-15.

Table 6-15: Cost of hardware, equipment, components and maintenance for TM 1 and TM 2

Total hardware, equipment and component cost	
Test Model 1	Test Model 2
R 24,858,314.85	R 12,523,880.02
Maintenance cost	
Test Model 1	Test Model 2
R 3,728,747.23	R 1,878,582.00

Using the costs from Table 6-15, Table 6-16 shows the cost of installation and maintenance for TM 1 and how these costs are discounted to present year values for the 20 year assessment period. Table 6-17 shows these costs for TM 2. Costs were discounted using Equation 6 and maintenance occurs every 2 years.

Table 6-16: Installation and Maintenance costs for Test Model 1

	Test Model 1		
Year	Installation cost	Maintenance cost	Discounted to year 0
End year 0	R24,858,314.85	R0.00	R23,016,958.19
1	*****	R0.00	R0.00
2	*****	R3,728,747.23	R3,196,799.75
3	*****	R0.00	R0.00
4	*****	R3,728,747.23	R2,740,740.53
5	*****	R0.00	R0.00
6	*****	R3,728,747.23	R2,349,743.25
7	*****	R0.00	R0.00
8	*****	R3,728,747.23	R2,014,526.11
9	*****	R0.00	R0.00
10	*****	R3,728,747.23	R1,727,131.43
11	*****	R0.00	R0.00
12	*****	R3,728,747.23	R1,480,736.83
13	*****	R0.00	R0.00
14	*****	R3,728,747.23	R1,269,493.16
15	*****	R0.00	R0.00
16	*****	R3,728,747.23	R1,088,385.77
17	*****	R0.00	R0.00
18	*****	R3,728,747.23	R933,115.37
19	*****	R0.00	R0.00
20	*****	R3,728,747.23	R799,996.03
TOTAL =	*****	R37,287,472.28	R40,617,626.43

Table 6-17: Installation and Maintenance costs for Test Model 2

	Test Model 2		
Year	Installation cost	Maintenance cost	Discounted to year 0
End year 0	R12,523,880.02	R0.00	R11,596,185.20
1	*****	R0.00	R0.00
2	*****	R1,878,582.00	R1,610,581.28
3	*****	R0.00	R0.00
4	*****	R1,878,582.00	R1,380,813.85
5	*****	R0.00	R0.00
6	*****	R1,878,582.00	R1,183,825.32
7	*****	R0.00	R0.00
8	*****	R1,878,582.00	R1,014,939.40
9	*****	R0.00	R0.00
10	*****	R1,878,582.00	R870,146.95
11	*****	R0.00	R0.00
12	*****	R1,878,582.00	R746,010.76
13	*****	R0.00	R0.00
14	*****	R1,878,582.00	R639,583.99
15	*****	R0.00	R0.00
16	*****	R1,878,582.00	R548,340.18
17	*****	R0.00	R0.00
18	*****	R1,878,582.00	R470,113.32
19	*****	R0.00	R0.00
20	*****	R1,878,582.00	R403,046.40
TOTAL =	*****	R18,785,820.03	R20,463,586.66

Tables 6-16 and 6-17 show year end values. As equipment takes one year to install, the installation is completed at the end of year 0. Maintenance therefore starts at the end of every second year, starting at the end of year 2 and carrying on to the end of year 20.

6.6.2 Staff salaries

The analysis conducted in Section 6.6.1 is not done for staff salaries over the 20 year period. This is because the annual salary of citizens in South Africa does not have a constant increase over time. The annual salary fluctuates in South Africa and using the economic indicators from Equations 1 to 4 would not provide veritable results. Furthermore, a compounded or simple interest increase or decrease for salaries will not provide accurate results since there are many other factors that contribute to the final salary an employee receives, such as bonuses, amount of time working, company success and market share, among other factors. A discussion relating to staff salaries is therefore based on the salaries at the end of year 1, previously determined in Chapters 4 and 5 for TMs 1 and 2 respectively. These are:

- TM 1: Annual staff salary of R6,539,744.00.
- TM 2: Annual staff salary of R7,419,744.00.

6.6.3 Results and discussion thereof

After using Equations 1 to 4 with the discounted costs determined in Tables 6-16 and 6-17, the PWOC, Present Worth of Maintenance Cost and the Present Worth of TM 2's benefits over TM 1 were calculated. These are indicated in Table 6-18.

Table 6-18: PWOC, PW of Maintenance Cost and PW of Benefits

	Test Model 1	Test Model 2
PWOC	R40,617,626.43	R20,463,586.66
PW Maintenance Cost	R17,600,668.23	R8,867,401.45
PW Benefits (TM 2 over TM 1)	R20,154,039.77	

The PWOC of maintenance cost is the sum of the discounted maintenance costs for the 20 year analysis period. The PW of benefits that TM 2 has over TM 1 is the difference in discounted maintenance cost between TM 1 and TM 2 after the 20 year period.

From this, the PWOC, B/C Ratio, IRR and NPV can be calculated. These indicators were determined for TM 2 so that the lifecycle cost of TM 2 can be compared to TM 1. Table 6-19 provides these indicators.

Table 6-19: PWOC, B/C Ratio, IRR and NPV for TM 2

PWOC (TM 2)	R20,463,586.66
B/C Ratio (TM 2)	1.74
IRR (TM 2)	4%
NPV (TM 2)	R8,557,854.57

The results obtained for the economic indicators collectively indicates that TM 2 is the more economically viable test model. The PWOC for TM 2 is almost half that of TM 1, indicating that TM 2 would incur less costs over the period of time assessed. This holds true for the Present Worth of maintenance cost as well, which indicates that double the amount of money will be spent on maintenance for TM 1 as opposed to TM 2. A B/C ratio of more than 1 supports the claim that TM 2 is more economically feasible than TM 1. The B/C ratio of TM 1 to TM 2 calculated means that TM 2's benefits exceeds its costs over the analysis period and that TM 2's benefit is 1.74 more than the initial cash outflow.

The IRR is the discount rate that makes the NPV zero (Corporate Finance Institute, 2020). The IRR is determined by assessing the cash outflow (initial cost of hardware, equipment and components, set to a negative value since it is money being spent) and annual maintenance value (set to positive since this is what the initial payment is being compared to). TM 2's positive IRR indicates that the initial cost of creating TM 2 provides a return value. Since the IRR is positive, this shows that the NPV, which is also positive for TM 2, is achieved by obtaining money at a rate of 4%. Following this, the NPV value for TM 2 indicates that the series of cash flows for maintenance over the 20 year period will yield a positive result (meaning that TM 2 is a better investment option over TM 1) and that TM 2 is the more economically viable test model for Stellenbosch. It is important to note that majority of the maintenance cost would be spent on IMS vehicle maintenance and that overflow money not spent can be used as bonuses for employees, future maintenance or put in an emergency trust in the event that normal business is stopped due to unforeseen reasons. Another reason why TM 2 is preferred over TM 1 is because less components are installed on roadways. When a component is installed, it has to be maintained. Since TM 2 has less physical infrastructure installed, less maintenance cost is incurred.

When assessing the salaries paid to employees between the two TMs, the initial perception would be that TM 1 will be cheaper over the period of 20 years because less money is spent on salaries. There are a few considerations relating to salaries, which are:

- Due to the fluctuating salary rates in South Africa, the annual salary paid to employees will be different based on the job done. FCD software specialists and UAV pilots may earn less in the future as UAVs are being used more frequently in various fields, which would reduce the demand for UAV pilots for traffic management since an individual from a different field can be employed.

- The difference in salaries between TM 1 and TM 2 is R880,000.00 in the first year. Although this value seems high, it is relatively low compared to the total cost of TMs 1 and 2. This motivates the decision to disregard the determination of economic indicators for salaries.
- Although the salaries related to TM 2 are higher than TM 1, TM 2 provides the possibility of staff reduction. Throughout the analysis period, the use of FCD may be efficient enough to replace CCTV cameras entirely, reducing the total Cost to Company (CoC) for employee salaries.

6.7 Operations centre design considerations

A detailed design of an operations centre is not provided in this study. However, some basic principles and considerations are provided.

Apart from the traffic management operations that have been assessed in this study, management for the following functions should be accounted for and space should be allocated for these functions in the operations centre:

- **Public transport management**: This includes management and correspondence with the appropriate stakeholders and relates to management of bus and rail operations. A section of the operations centre should be allocated for public transport management, safety and security and maintenance. If this sectioning is not possible, officials at the operations centre in Stellenbosch should be in contact with public transport authorities to ensure a steady flow of information so that efficient traffic management can be provided to the entire road network.
- **Traffic services**: Existing traffic law enforcement personnel should work in cohesion with the operations centre and a section of the centre should accompany law enforcement.

A locality plan and building design has not been conducted for this study apart from the proposed location for IMS unit deployment described in this study. This study is meant to assess the implementation of traffic management processes to a small city environment.

For Stellenbosch, the basic elements required at the operations centre are:

- **Work stations for operators**: These workstations should be spaced adequately to provide operators with comfort. Workstations should also be equipped with the necessary hardware (monitor, keyboard, and mouse) and software (for traffic management and FCD assessment) required for traffic management processes.
- **Video wall**: The video wall should be adequately sized so that CCTV camera footage can be viewed when incidents occur. The wall should be white with projectors displaying footage on it. CCTV operators should face towards the wall.
- **Server room**: Space should be allocated for the server room and accompanying hardware. The server room should be easily accessible and spacious enough so that maintenance relating to the server can be done efficiently.
- **Offices for manager and supervisors**: Office space should be allocated for supervisors and managers and must be situated above the room containing operators work stations and the

video wall, so that incidents projected onto the video wall can be identified by the manager and reacted to.

- **Office space for different functions**: Each different function accounted for in the operations centre should have its own room. This is so that employees within functions can work effectively and that each function can have one representative who participates in scheduled stakeholder meetings.
- **Boardroom**: At least one boardroom is required for scheduled meetings between representatives of different functions. This boardroom should include a modern boat-shaped table, a projector and a monitor for presentations, and enough chairs for everyone attending a meeting.

6.8 Conclusion to functionality assessment

After an expansive analysis of the traffic management capabilities of TM 2 and its components, the areas where TM 1 and TM 2 differ were determined. The difference in the level of traffic management provided to Stellenbosch by hardware used in TM 1 and TM 2 was determined and the affect that reducing the number of physical traffic management components has on the overall traffic management of Stellenbosch was discussed.

Following this, the implementation of FCD was assessed. Firstly, the choice for the location of the IMS Unit Station was assessed by determining travel times from the Unit Station to areas throughout the study area with FCD. A travel time map was created which showed how far IMS units could travel in 5, 10 and 15 minutes from the Unit Station. In addition to this, a discussion of the travel times and speeds associated with the morning and afternoon peaks as well as the base time period was provided. In addition to this response time analysis, the delay in response time between TM 1 and TM 2 was determined. This included an analysis of how UAVs affect the response time of IMS units for incidents occurring within and further than a 7 km radius of the response unit deployment location. It should be noted that the response time for TM 2, while higher than TM 1, would be shorter and more accurate than the response time with no TMC in place.

An assessment of the traffic management provided by UAVs as opposed to CCTV cameras is also provided. Finally, an economic evaluation for TM 1 and TM 2 was provided which highlighted the economic benefits of implementing TM 2 instead of TM 1. Factors that should be considered relating to the design of an operations centre for traffic management were also highlighted and important characteristics that an operations centre should have were provided.

Chapter 7: Conclusion and Recommendations

7.1 Conclusion

The aim of this research study was to determine a cost effective method of managing traffic and traffic incidents for a small city environment by assessing the effectiveness of two Test Models (TM 1 and TM 2) with different levels of traffic management functionality. After a detailed review of literature relating to traffic management systems and practices, these two TMs were created and implemented to the study area of Stellenbosch. TM 1 consisted of four sections: (1) An Arterial Management System (AMS) which provided traffic management and obtained information relevant to traffic on the arterial network surrounding Stellenbosch by using CCTV cameras, Variable Message Signs (VMSs), Vehicle Detection Sensors (VDSs) and Environmental Sensing Stations (ESSs); (2) An Urban Traffic Management (UTM) system which consisted of CCTV cameras and VDSs; (3) An Incident Management System (IMS) consisting of incident response units, light and heaving towing units; and (4) A description of how traffic information is managed. Following this, TM 2 was created by reducing the number of components in TM 1 and introducing the use of Floating Car Data (FCD) and Unmanned Aerial Vehicles (UAVs) in order to provide a more cost-effective method of traffic management to Stellenbosch. A cost breakdown was then provided for both TM 1 and TM 2 and the traffic management functionality that TM 2 provided compared to TM 1 was determined. Finally, an economic evaluation for TM 1 and TM 2 was provided where the Present Worth of Costs (PWOC), the ratio of Benefits to Costs (B/C Ratio), Internal Rate of Return (IRR) and the Net Present Value (NPV) economic indicators were calculated.

From the results obtained, it was found that the costs associated with TM 1 after the first year is R31,398,058.85 and R19,943,624.02 for TM 2. TM 2 was therefore found to be 36.5% cheaper to implement than TM 1. The level of traffic management functionality lost in TM 2 due to reducing the number of physical components on the road network from TM 1 was determined and regained with FCD with UAVs and, following assessments and discussions made relating to the benefits that FCD and UAVs provide in addition to this regained functionality, it can be concluded that TM 2 is the better option for traffic management in Stellenbosch. The efficient collection, analysis and use of FCD in a small city such as Stellenbosch can serve as a pioneering method of traffic management in other small cities in South Africa. This decision is motivated with the four economic indicators that indicates collectively that TM 2 is the option that is more economically viable.

7.2 Achievement of research objectives

For this study, three research objectives were identified in Section 1.3 of Chapter 1. This research project aimed to achieve these objectives. Table 7-1 indicates whether the research objectives were achieved and the relevant chapters where these objectives were met.

Table 7-1: Achievement of objectives and chapters where these objectives are met

Objective	Objective achieved	Chapter
1. Evaluate the systems and processes that traditional TMCs are comprised of through an extensive review of literature. Thereafter evaluate how traffic is managed with Unmanned Aerial Vehicles (UAVs) and how Floating Car Data (FCD) is used for traffic management purposes.	✓	**Chapter 2**
2. Develop two TMC models that assesses different methods of traffic management.	✓	**Chapter 3** **Chapter 4** **Chapter 5**
3. Determine the level of functionality that is lost due to limited infrastructure in TM 2, including an economic evaluation of TM 1 and TM 2.	✓	**Chapter 6**

7.3 Recommendations

This study identified the difference in traffic management capability between a model based on traditional traffic management practices and a different model using a reduced number of components in addition to FCD and UAVs. From the analysis of TMs 1 and 2 created in this study, it is recommended that TM 2 be implemented in Stellenbosch. This decision is based off the functionality assessment and economic evaluation represented in Chapter 6.

Firstly, it is recommended that pilot studies be conducted that assesses the capability of traffic management of the system defined in TM 2. This would determine how well-equipped the components, FCD and UAVs used for traffic management in Stellenbosch would be to monitor and manage traffic. Secondly, it is recommended that different types of UAVs with varying battery lives be tested in Stellenbosch so that a longer flight time can be achieved. A UAV with a longer battery life can be flown at a lower speed or for a longer duration so that more traffic information can be obtained with greater clarity. Thirdly, it is recommended that extensive site investigations be conducted so that precise locations for infrastructure can be determined and factors such as the direction CCTV cameras face relative to the sun, precise field of view of cameras, optimal location for weather stations and VDSs and calibration of UAV flight path can be optimised. Finally, it is recommended that a physical model of the infrastructure be built to visually assess the impact that different traffic management components have on a small city environment level.

7.4 For future research

Certain aspects were neglected from this study as it was not within the defined scope. Therefore, future research in the following areas is recommended:

- The assessment and determination of how effective TMSs are considering the types and amount of traffic data available to TMCs.
- In-depth cost calculations can be conducted including a detailed maintenance calculation for each component used since maintenance cost might be different for different components.
- Automated signal changes when emergency response units are approaching a signalised intersection to reduce incident response time.
- Implementation of UAV traffic management on a full time basis and not just for peak periods.
- Introduction of incident recognition algorithms for UAVs. This includes the use of Artificial Intelligence (AI) to allow drones to autonomously fly a specified path and detect incidents, to reduce response time to traffic-related incidents. AI could also be used for UAV-to-UAV communication to calibrate positioning and flight patterns of a UAV network.
- The implementation of a cloud-based traffic management system which has no physical infrastructure (no CCTV cameras, weather stations or VDSs) since technological disruptions are taking place and a cloud-based system would be more adaptable to developing environments.

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